INTEGRATED ENERGY-ENVIRONMENT PLANNING: Initial Results from Senegal

Preliminary Report prepared for the Seminar on Energy Management Policy and the Environment[1]

Michael Lazarus
Stockholm Environment Institute-Boston (SEI-B)
and
Souleymane Diallo
Environment and Development in the Third World (ENDA-TM), Dakar

July, 1992

Summary

This paper addresses a case study of energy-environment interactions in Senegal that is currently underway as the first phase of a joint SEI-ENDA project designed to build institutional capacity for integrated energy-environment planning in Africa. This project is funded jointly by the United Nations Environment Programme (UNEP), and the International Development Research Centre (IDRC), SEI, and ENDA, and involves the participation of the Senegal Ministry of Industry and Artisans and the Ministry of Planning.

Senegal faces two energy issues common to many African countries: high import dependence with consequent foreign exchange costs, and high levels of biomass energy use amid a declining wood resource base, with detrimental impacts, particularly on rural communities. Senegal also confronts issues more unique to the Sahelian West African region: highly vulnerable semi-arid ecosystems, relatively poor endowments of energy resources, and, as a result, high energy prices, particularly for electricity.

While urbanization is rapidly increasing, and with it, the consumption of fossil fuels, Senegal's most widespread and immediately apparent energy-related environmental issue remains the local availability of biomass, and the land degradation resulting from agricultural expansion and the charcoal trade. At the same time, with considerable land area near sea level, and a dry Sahelian climate, Senegal is highly vulnerable to the potential effects of global climate change. Salt water intrusion is already a problem in many areas. Significant sea level rise could result in severe damages to many key areas, including biologically-rich island ecosystems of the Saloum region, important coastal tourist areas, and low-lying rice fields in Senegal's richest farming area, the Casamance.

1_ This draft report reflects initial, interim results of the Senegal energy-environment analysis project. Many aspects have not yet been fully reviewed by all parties involved, and in particular, the Senegalese government and thus do not necessarily reflect official positions. Since the analysis is still underway, the results and conclusions should be considered interim, and subject to revision as the project evolves. The authors would appreciate reader comments and suggestions.

On a per capita basis, Senegal emits approximately one-quarter the world average greenhouse gas emissions from all sources; its per capita fossil fuel carbon dioxide emissions are one-tenth the global average.[2] As country of about 7 million inhabitants, Senegal's contribution to the global increase in heat-trapping gases would thus appear very small indeed. Nonetheless, several political and economic factors suggest the importance of a closer scrutiny of greenhouse gas emissions and the options for reducing them. While the study described here covers greenhouse emissions as part of an overall energy-environment assessment, an additional study is now underway to explore the cost of GHG abatement in West Africa.[3] Together, these studies can help in the analysis of costs and benefits to Senegal of various burden or target sharing regimes, preparation and contribution to on-going international negotiations, and the identification of "no-regrets" strategies that could reduce energy costs in the country regardless of climate benefits.

To date in West Africa, environmental considerations in the energy arena have been largely oriented toward reducing the impacts of biomass energy use through interfuel substitution, improved stove and kiln efficiency, and improved woodland management. Other environmental issues, such as local and urban air quality and global climate change have until recently received far less attention, and the interaction and tradeoffs among these environmental issues, even less so.

This paper explores the energy and environmental dimensions of a few proposed energy strategies (butanization, improved efficiency, and hydro additions) for Senegal. We review some of the important energy-environment questions, develop a set of preliminary scenarios relevant to these concerns, and investigate some of their energy and environmental repercussions. We do so using a quantitative analytical framework, and begin to explore how useful such numerical methods can be, as well as their limitations in an African context. In doing so, we develop a set of emission factors for use in Senegal, based on past studies and an Environmental Data Base system that could be useful for other studies in Africa as well as in other regions. Finally, we briefly address ways to integrate the often incommensurate environmental and economic costs and benefits for environmentally-informed decision-making.

In summary, we find that policies intended to promote the use of fossil fuels in some circumstances, in particular the substitution of liquid petroleum gas (LPG) for charcoal in households, can actually reduce greenhouse gas emissions, while contributing to the improvement of more important near-term environmental problems

---

[2] Based on estimates for 1988 by the Stockholm Environment Institute (Subak et al., 1992). Average per capita emissions in 1988 were 6.9 tonnes (world) and 1.7 (Senegal) tonnes CO2 equivalent GWP, and 3.9 (world) and 0.4 (Senegal) tonnes CO2 alone from fossil fuels. Global warming potential (GWP) attempts to reflect the contribution of various greenhouse gases, weighted according to their contibution to warming over a fixed time period. These figures reflect the most recent IPCC 1992 GWP estimates, which only cover gases that are known to contribute directly to warming (CO_2, CH4, N_2O, halocarbons). Due to greater uncertainty regarding their atmospheric chemistry, the IPCC no longer suggests GWPs for indirect contributors (NOx, HC, CO separate from its eventual CO_2 contribution). The previous 1990 IPCC GWPs, which included factors for these contributors, are used in some tables in this paper for comparison only, as many studies to date have used them.

[3] An additional regional study funded by the French government (Programme Energy-Environment Africa) has recently been initiated and, as part of this study, an analysis of the cost of reducing emissions will be made for several countries, including Senegal. ENDA is playing a central role in this program.

(e.g. rural ecosystem deterioration) in an African country such as Senegal. At the same time, the impact of LPG substitution on increasing the oil import bill is relatively small compared to other petroleum product usage. Over the set of combined policies considered here, oil imports decline up to roughly 30 percent in 2005 compared with the reference case, while reducing future emissions and indicators for several categories of environmental impact. Overall, the integrated energy-environment scenario approach can reveal straightforward interactive and combined policy effects that might otherwise be missed in a single project or policy approach.

Table of Contents

1. Study Background

The incorporation of environmental considerations has become an important new area for energy planners. Energy use and production can be major sources of serious environmental impacts. These impacts, in turn, can threaten the overall social and economic development objectives that energy use is thought to promote. Examples of such dilemmas abound. At the regional and global level, fossil fuel consumption is helping to cause acid rain and global warming. At the local level, reliance on biomass fuels is rapidly depleting forests in several areas, leading to soil erosion, loss of habitat, and deterioration of living standards.

In Africa, success in resolving energy-environmental questions is critical. Rapid changes are occurring in both rural and urban areas that will affect generations to come. Land clearing for agriculture and energy have local impacts and potential global climate impacts. The rapid expansion of urban areas is changing energy use patterns, as more people come into the cash economy and commercial fuels (electricity, petroleum products, etc.) become options for displacing traditional fuel use (wood, charcoal, crop residues, etc.). Such so-called *energy transitions*, when they occur, will have significant effects on air, water, and soils, locally and globally. At present, there are great opportunities for directing energy use and production patterns toward those that, recognizing environmental externalities, will help to minimize long-term economic and social costs. The alternative is energy development uninformed by environmental considerations, as is often still the case in Africa, as it is elsewhere.

Many African countries are currently building their energy and environmental planning capabilities. However, these institutions are generally relatively new and in need of important resources: training, experience, and useful methods adapted to local conditions. Environmental analyses have tended to be few, on an ad-hoc basis, as needed for project approval, often at the behest of donor agencies. The lack of local studies and data can impose serious constraints, as can the near-term and growth-oriented focus of developing economies. Applicable methods must consider these factors.

Over the past few years, the Energy Programme of ENDA has been very active throughout Africa, helping national planning institutions to meet these essential needs. Since 1985, ENDA has run annual two-month training courses in energy planning, and has trained staff from government energy planning institutions in most African countries. More recently, ENDA has added two additional two-week courses, one on energy policy, and another specifically devoted to energy planning tools and methodology. The ENDA Energy Programme also provides assistance and advice to African energy agencies on data collection, surveys, construction of energy balances, and other planning-related tasks.

Toward the goal of implementing useful analytic methods, computerized decision support systems can be very useful tools. They can help in the analysis of data, development of projections, and evaluation of alternative scenarios. One such tool is the Long-Range Energy Alternatives planning system (LEAP), used by energy ministries and researchers in over 20 countries, including several in Africa. The United Nations Environment Programme (UNEP) and the SEI-B are in the final phases of a joint project to add to LEAP the capacity to undertake environmental analysis. A central part of this project has been the development of the Environmental Data Base (EDB) of LEAP, containing an extensive collection of emission and direct impact coefficients for all energy producing and consuming processes and technologies. EDB is linked with LEAP so that scenarios can be developed to evaluate relative environmental emissions associated with alternative energy futures. As part of the UNEP/SEI-B project, LEAP and EDB are being applied in Costa Rica, Tanzania, and several other countries in addition to Senegal, with the emphasis on refining the methods and the accompanying Environmental Data Base.

This paper describes in part some of the initial work of ENDA and SEI-B to develop and disseminate systematic methods for incorporating environmental concerns into national and regional energy planning in the African context. Such methods are essential for understanding the processes of environmental degradation and the development of energy policies and projects that can lead to a sustainable future. There is currently a lack of tools suited to this task adapted to the conditions found in many developing countries. A major part of the project involves development and refinement of the LEAP/EDB system in a concrete application in Senegal. However, methods alone are insufficient. Government institutions and energy planners must be capable of effectively using these methods and of enacting appropriate policies. Therefore, as a major part of the project, ENDA and SEI-B are working with local African energy institutions through country level applications and assistance, in this case the Energy Directorate and the Ministry of Planning in Senegal.

This project is being implemented through a series of phases. Phase I, the subject of the remainder of this report, concerns the development of preliminary energy and environment scenarios for Senegal. This phase has also involved meetings with government officials to link this analysis with national level policy and institutional development, including the transfer of computer tools. During Phase II, more in-depth development of energy and environmental data will be undertaken to deepen the analysis begun in Phase I, and to translate it into concrete policy recommendations. Through the ENDA Energy Programme, these methods will be transferred to other African countries, many of whom have already requested such assistance. These environmental analysis methods are also being incorporated into ENDA's regional training programs.

2. Background: Senegal

Situated on the far Western coast of Africa, Senegal also lies within the Sahelian region hard hit by many years of drought, particularly acute in the 1970s. With 7 million inhabitants, and a total land area of just under 20 million hectares, Senegal has a population density somewhat higher than the African average of 217 persons per thousand hectares. (World Resources Institute, 1992) Much of this population is concentrated within a few cities and river basins. Approximately 40 percent of the population lives in the rapidly growing urban areas, over half in the Dakar metropolitan area. At current trends, the nation will be predominantly urban within the next 10-20 years.

The average per capita GDP of approximately $700 per capita in 1989 is considerably higher than in most other countries in the surrounding West African region. Over half of GDP is generated by service activities, most notably tourism. Agriculture, dominated by peanuts, millet, and sorghum, accounts for about one-fifth of GDP. While the increasingly export-oriented fishing industry represents less than 4 percent of GDP, it produces about one quarter of total export earnings. Other important industries, including phosphate mining, chemicals, cement, and vegetable oils, account for another quarter of gross product.

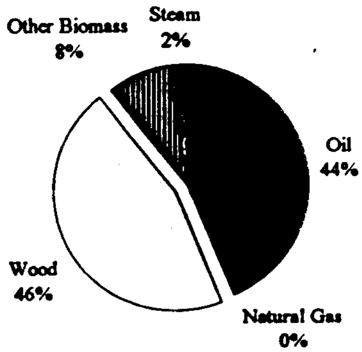
2.1 Senegal energy issues:

Aside from plentiful solar radiation, Sahelian countries are known for their paucity in primary energy resources. While Senegal currently exploits small domestic onshore natural gas and crude oil deposits, proven reserves can make only minor contributions to overall national energy supply. Off-shore oil exploration activities have identified probable off-shore reserves of heavy crude, but there are no imminent plans for production. Lignite and peat resources have also been identified, with studies initiated on the potential use of peat and peat-charcoal as a domestic fuel. (Republique du Senegal, 1992)

Two international rivers, the Gambia and Senegal, flow through and along the country's border, offering a substantial hydro potential of 1000 MW, over 6 times the current peak load on Senegal's main grid system. Much of this potential lies in the Senegal River basin and requires ongoing coordination among Senegal and neighboring Mauritania and Mali for the full realization of joint projects. Two dams have already been constructed in Mali (Manantali and Felou), and plans appear to be underway for installing 200 MW of turbines and constructing transmission lines. However, similar plans have been delayed in the past due to political issues, and thus they are not included in our reference case described below.

Senegal's official energy policy, as articulated in RENES (Senegal Energy Strategy), focuses clearly on the two main problems noted earlier. In rough translation: "Supply and demand contribute to excessive dependence on costly petroleum and woodfuels, of which intense usage threatens the national environment". (p. 59, Republique du Senegal, 1992) The main policy objectives are thus to "reduce dependence on oil and pressure on wood resources."

Primary Energy Supply Mix, 1988



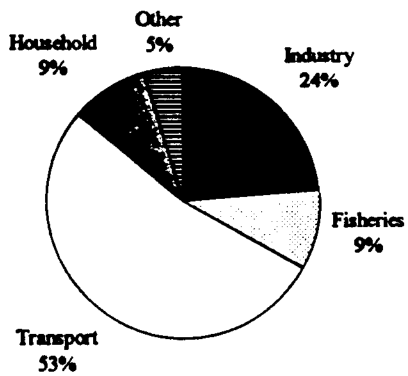
Together, oil and biomass accounted for 98 percent of Senegal's 1988 primary energy supply, as shown. Biomass energy supply, however, is far more uncertain than oil, and could be higher than 45 percent, due to unreported charcoal production. Between 1980 and 1988, oil imports accounted for 17 to 28 percent of total imports, and from 26 to 59 percent of total non-energy export receipts. (ENDA-TM, 1990)

On a per capita basis, Senegal's annual primary commercial energy consumption of about 5 GJ (0.1 TOE) is less than one-tenth the world average of 57 GJ (1.4 TOE), but slightly higher than in most non-oil exporting Sub-Saharan African countries. (World Resources Institute, 1992) With the exception of self-generation from crop wastes (bagasse and peanut shells) and steam by-products of sulfuric acid production, all electricity is produced from petroleum products, nearly all of which is imported. This, in part, accounts for the very high electricity prices paid by Senegal consumers, over $0.2 U.S. per kilowatt-hour. (Older inefficient equipment is another factor.) The parastatal electric utility, SENELEC, operates a main grid network among the major cities of coastal Senegal (Kaolack-Dakar-St. Louis), and several secondary isolated stations and networks. High prices also help to explain why over 16 percent of total electricity in 1988 was generated by private industrial producers.

A single refinery (SAR) produced approximately 700,000 TOE of petroleum products, compared with 800,000 TOE consumed in 1988. In addition, on a net basis, Senegal imports most petroleum products, except diesel/gasoil and aviation gas. With the current oversupply of world refinery capacity, continued operation of the SAR refinery has been questioned, but is nonetheless likely to proceed.

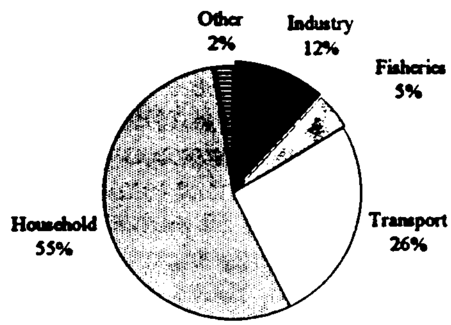
Comparing across sectors as shown, transport accounted for the largest share of 1988 commercial energy consumption, followed by industry (over half as fuel oil), and households (half electricity, half LPG/kerosene). Senegal is a major hub for West African air traffic, which accounts for over 40 percent of transport sector energy consumption and the dominance of the transport sector in the national energy balance. The fisheries sector, an important source of foreign

1988 Commercial Energy Consumption by Sector



exchange earnings, accounts for almost 10 percent of total commercial energy consumption.

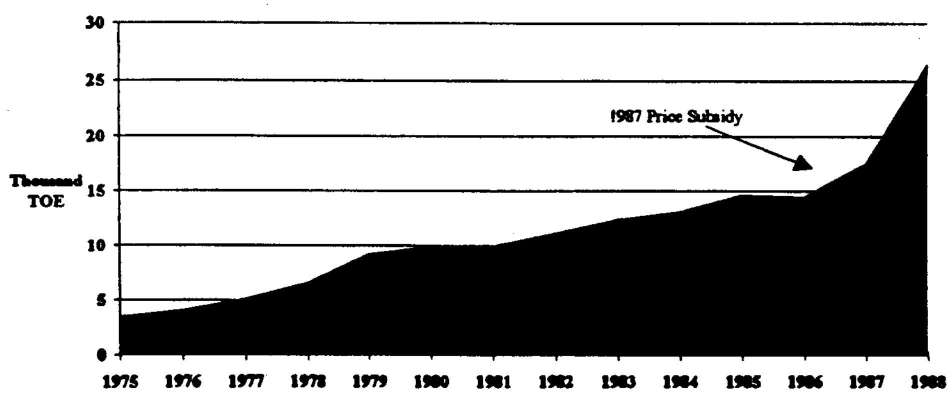
1988 Final Energy Consumption by Sector (incl. biomass)



When so-called traditional fuels -- firewood, charcoal, and agricultural residues -- are included in the picture, the household sector accounts for over half of total energy use. Urban household consumption is dominated by charcoal use for cooking, with smaller amounts of electricity, wood, LPG, and kerosene, while rural consumption is almost entirely in the form of firewood for cooking purposes.

Several recent trends are worth emphasizing. LPG consumption, over 90 percent accounted for by household consumption, has recently exhibited very rapid growth. While the LPG consumption grew only 7 percent from 1985 to 1987, in July 1987 increased price subsidies resulted in a decline in LPG prices by 30 percent (for small consumers). From 1987 to 1988, LPG consumption grew by nearly 50 percent. (ENDA, 1990) Meanwhile, overall petroleum product consumption has stayed relatively constant from 1985 to 1988; LPG still only accounts for 3 percent of the total. Meanwhile, electricity use has grown steadily in recent years (6% per year, 85-88). For a fuller picture of national energy use and supply, the 1988 energy balance, developed by ENDA, is included as Annex 1.

Household LPG Consumption Trends



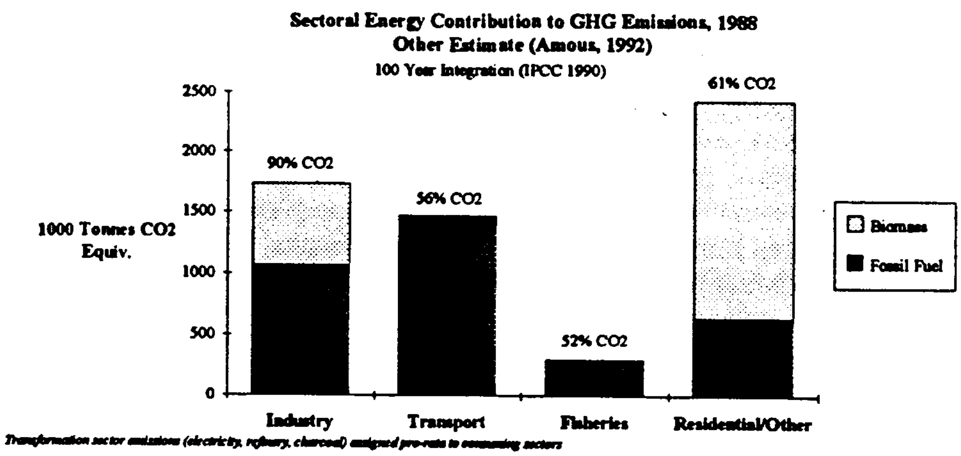
Source: ENDA, 1990; World Bank, 1989

2.2 Energy-environment issues in Senegal

Environmental discussions in Senegal have been dominated by concern for the declining forest cover, soil erosion, local climate change, and interactions with agricultural and pastoral activities of rural people. Some of these issues are reviewed in the adjoining text box, while the relationship between biomass energy use and deforestation is explored in Section 6.2. below.

Other issues have only begun to enter into energy planning discussions. For instance, it has been noted that in electricity supply planning "with regard to the questions of energy efficiency and of environmental impact, they are 1) raised only by energy users, and 2) for the time being, relatively, to not say totally, absent from the debate." (Girod et al, 1991) At the same time, the Senegal report to UNCED notes that uncontrolled industrialization and various pollutants (e.g. auto emissions) render living conditions more and more precarious, particularly around Dakar.

Urban air pollution, increasingly severe in many developing urban areas worldwide, could pose greater problems with anticipated growth and traffic congestion in urban areas, particularly in Dakar. *Acid precipitation* does not appear to be a problem at present, and is unlikely to become one in the foreseeable future, barring vary rapid growth accompanied by decisions to exploit or import large amounts of coal.[4] *Indoor air pollution*, very much related to household use of biomass fuels for cooking, also poses serious health risks. Finally, proposed hydroelectric development presents potential risks to flooded and downstream areas, as well as to areas that might be affected by long-distance, high voltage transmission lines. We return to these and other questions in the development of environmental data in Section 6.



With increasing international attention on greenhouse gas abatement strategies, the capability to quantify greenhouse gas emissions has become increasingly important. To this end, ENDA, and several other institutions including SEI co-sponsored a regional African workshop in April 1992 on tools and methods for global warming analysis. Preliminary results of this paper were presented together with an assessment of current greenhouse gas emissions from all sources. (Amous, 1992) These current emissions estimates, presented for the energy consuming sectors below, were based largely on standard IPCC emission categories, and on the assumption that all biomass energy use is non-renewable (i.e. leading to deforestation), resulting in

4 Some Senegalese river basin soils already suffer from acidification (Republique du Senegal, 1992), therefore the sensitivity to sulfur and nitrogen oxide emissions could be high in some areas.

LOCAL CLIMATE CHANGE IN SENEGAL

Over the past 3 decades, climatic fluctuations have had a marked impact on terrestrial and aquatic ecosystems in Senegal. From 1960 to 1968, rainfall was normal or even slightly above the previous 30 year average in Sahelian regions. However, beginning in 1968 onward, several years of extreme drought conditions occurred. The 1970s witnessed a 60 percent drop in average annual precipitation in Northern Senegal, and appears to have resulted in an southward extension of the Sahelian zone. The total land area receiving 600 mm and less of rain increased from 77,000 km2 or 40% of total national land area in 1950, to 120,000 km2 or roughly 60% in 1980.

While the severity of the Sahelian drought of the 1970s may have since subsided to some extent, and with it various social and environmental impacts-- land degradation, famine, increased livestock mortality, and migration --, a climatic regime of persistent drought and climatic variability continues. Climatic feedbacks, such as the intensification of dry winds and sandstorms, increasing aerosol concentrations, only intensify the processes already underway.

Several human factors have been suggested as contributors to the process of land degradation and regional climatic change. Most frequently, they include overuse of grazing and pasture lands, expanding agricultural cultivation to marginal and ecologically fragile lands, brush fires associated with various rural activities, and charcoal production.

estimated high net carbon dioxide emissions, as shown above (over 40% of total energy-related CO2). Section 6 below reviews some important greenhouse gas emission factors in detail, as a further iteration to these estimates.

Senegal's report to UNCED sets out several broad policy goals to address environment and development goals related to the energy sector: reduced import dependence, improved energy efficiency in all sectors, improved household stoves , increased electricification, and improved energy planning and management. To this end, several projects and studies have already been undertaken, with new ones underway. They include a very extensive Industrial Energy Conservation project (mid80s), several urban household surveys and studies (World Bank, 1989; ENDA, 1991 to be published), numerous household stove projects, various oil and electricity sector planning studies, and an overall project to reinforce energy planning capacity (of which this study is a part).

3. Study Approach

The approach initiated here attempts to bring together the various energy strategies in a common framework where their impacts on many environmental factors can be reviewed. Indeed the energy-environment issues are too wide and deep to cover all aspects well, particularly at this initial stage. Thus, we focus on a handful of policies and the question of emission and impact measurement. What do the existing studies and data allow us to say, and how definitively?

We focus on the question of emission factors, in order to point out some of the potential pitfalls, and provide guidance in their application in a context such as Senegal's. Increasingly studies are being undertaken, typically in the context of global warming, acid precipitation (Asia), and urban air quality problems, that involve joining questions of energy technology and policy with those of environmental emissions and impact. Often, these studies look at only one problem, resulting in conclusions that fail to adequately incorporate concerns about related issues. For example, studies involving optimization models for reducing acid precipitation damages may prove insightful with regard to one environmental aspect of energy questions, but may ignore other concerns and constraints, and result in less than optimal resource allocation.

3.1. Steps in Integrated Energy-Environment Analysis

An idealized approach can be laid out here, based on the principles of least-cost, integrated resource planning. These principles involve considering, on equal footing all fuels and technologies, whether on the supply or demand side, for the provision of end-use services and amenities (hot water, lighting, transport, etc.), rather than of energy itself. They also involve the incorporation of environment issues, and the consideration a long term planning horizon (e.g. > 10 years), beyond, but not in isolation from the short-term issues that often dominate the planning realm.

The following six steps define a process for analyzing energy-environment issues, and formulating environmentally-informed energy policy:

1) <u>Investigate energy use patterns</u>: to establish a reliable database for projecting future energy needs, comparing technological alternatives, and evaluating policy impacts. Additional data collection activities may be identified and undertaken.

2) <u>Prepare demand projections</u>: to define a range of plausible policy-neutral scenarios that reflect "business-as-usual" and alternative evolution of demographic and macroeconomic factors.

3) <u>Investigate resource and technology options</u> for improving end-use services at the lowest societal cost, including environmental impacts. This step involves gathering data and judgement on various supply and demand options (new facilities, import/export options, efficiency improvements, fuel-switching). Cost curves can be used to compare various demand and supply options, as a screening measure for developing scenarios. Unlike integrated scenarios, cost curves, however, do not usually consider the interactive effects of a set of options implemented together.

4) <u>Collect environmental data</u>, related to environmental issues of local concern. In addition to gathering appropriate emission factors, this step involves establishing the relevant cause-effect linkages (e.g. biomass energy use ⇒ land clearing ⇒ deforestation), and characterizing the impacts more difficult to measure or quantify (e.g. ecosystem harm).

5) <u>Prepare integrated scenarios</u> to investigate alternative energy strategies. "What if" questions can be based on locally available options, and can reflect the real social, political, cultural, and institutional constraints that may exist in a country.

6) Analyze policy options and implications, to determine how the least cost, maximum benefit scenario can be achieved, and what additional costs might be involved (e.g. program/administrative costs, economic losses or gains due to taxation or subsidies, etc.).

It must be emphasized that this framework is iterative, as an initial set of scenarios may indicate the need for additional data collection, and the policy analysis process may in turn indicate additional scenarios that need to be evaluated. In the case of the Senegal study presented here, a "first run" through several of these steps has been completed.

A recent study for the United States, *America's Energy Choices*, provides a concrete example of a thorough energy-environment analysis along these lines. (UCS et al., 1991) A set of policies emphasizing efficiency improvements, fuel switching, and renewable energy, were found to result in present value savings of over $2300 billion over 40 years (1990 US$), in comparison with business-as-usual energy trends, plans, and policies. At the same time, these policies can reduce carbon dioxide, sulfur dioxide, and nitrogen oxide emissions by over 70 percent each, by 2030. In an earlier integrated planning study in Africa, energy policies for Kenya were reviewed with an emphasis on reducing pressure on natural forests and improving the provision of essential energy services, such as lighting to rural residents. (O'Keefe et al, 1984) In both cases, LEAP, as described below, was used as the organizing analytical framework.

3.2 Analytical Framework:LEAP/EDB

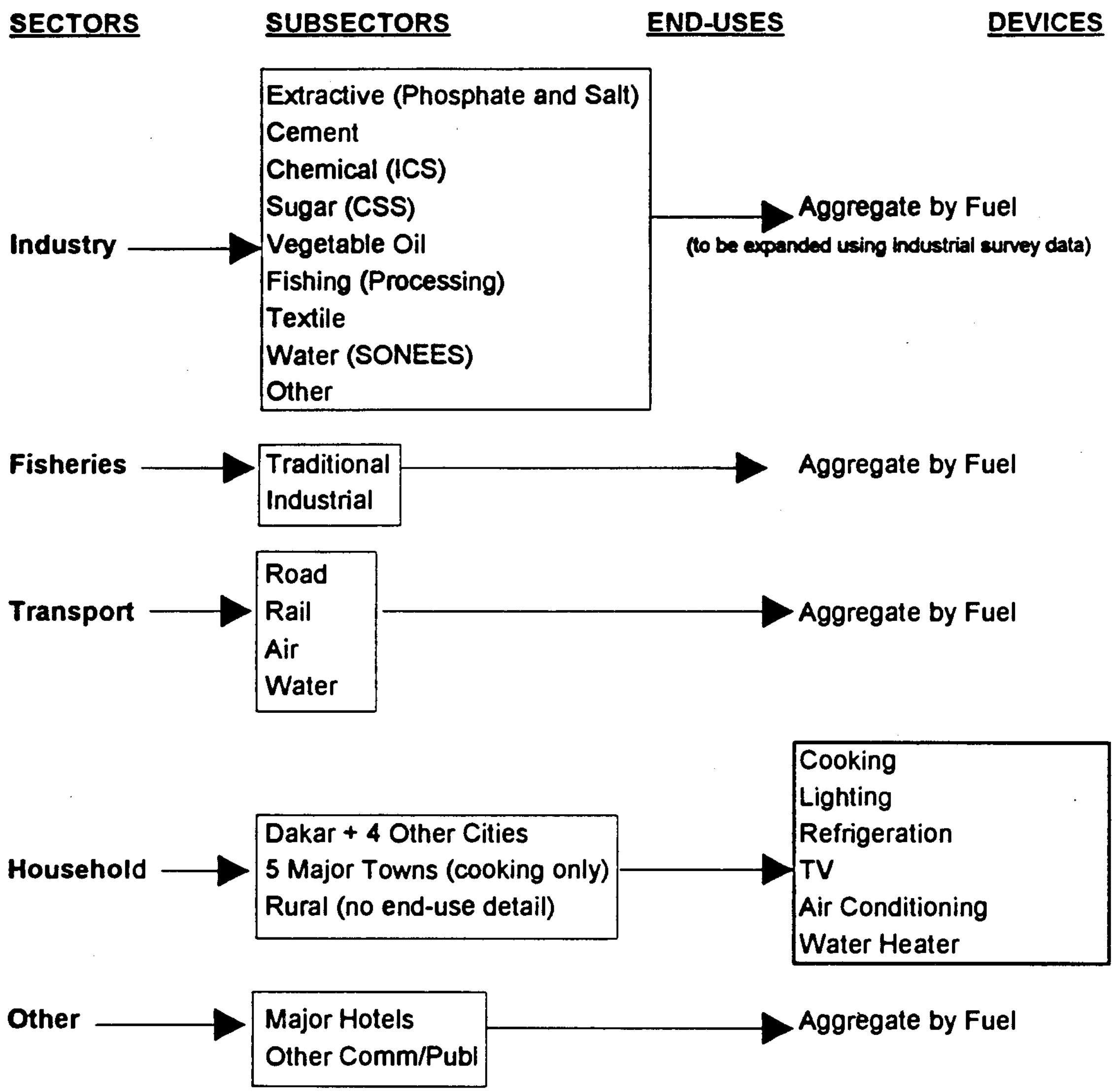
The Long-Range Energy Alternative Planning (LEAP) system provides the analytical tool for creating the energy and emission scenarios for the Senegal study described here. We also use the associated Environmental Database (EDB) as a source for specific emission coefficients. Together, LEAP/EDB comprise a computerized modelling system designed to explore alternative energy futures, along with their principal environmental impacts. As a flexible, model-building tool, model relationships and detail can be tailored to the local dynamics and data constraints of individual applications. A brief description and partial user list are included as Annex 2.

4. Modelling Senegal's Energy System

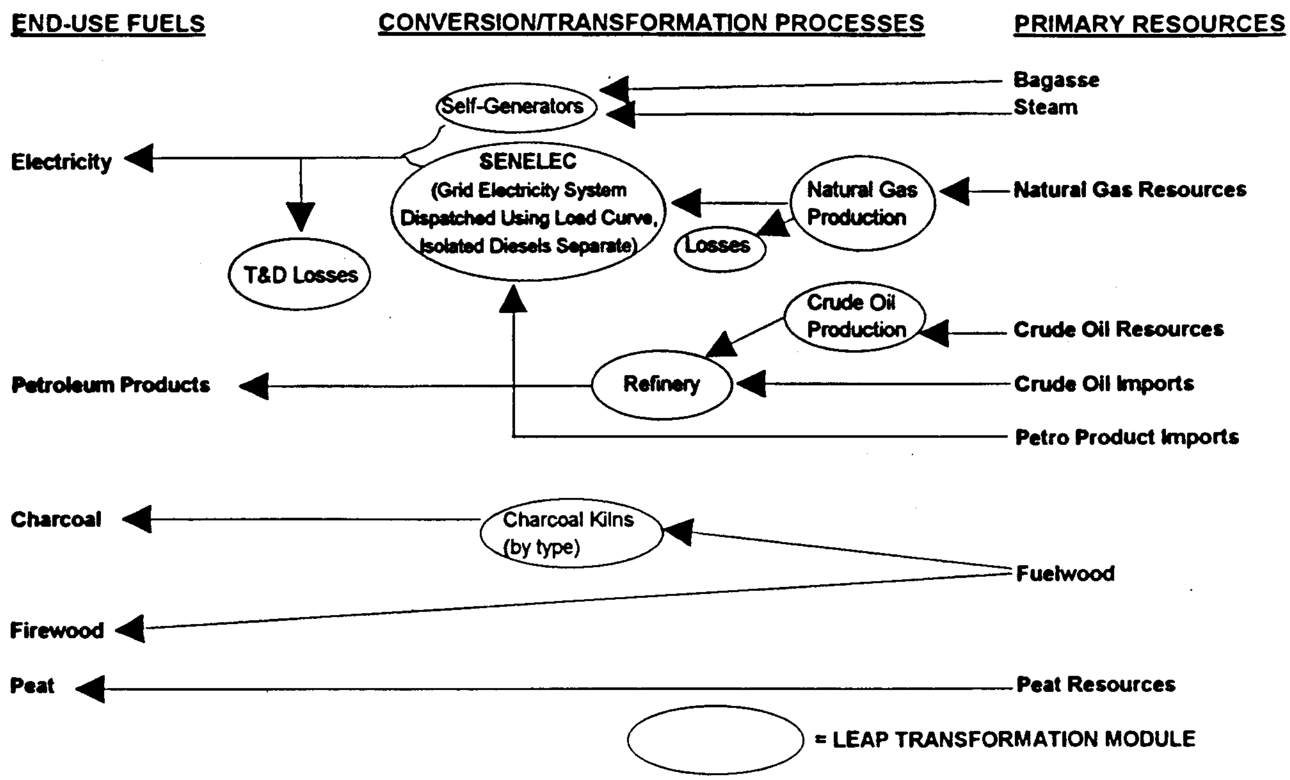
Data availability and the need to develop some rapid initial scenarios have dictated a rather simple model for Senegal's energy system. The schematic structure of the demand model is shown below.[5] Recent surveys by ENDA and World Bank (1989) guided the disaggregated structure of the household sector. Future household energy use is driven by saturation levels for various end-uses (cooking, lighting, refrigeration, etc.), fuel choices, changes in end-use efficiency, population growth, and changing numbers of persons per household. Each of these variables is exogenous. That is, they are based on determinations of future values that are outside the model (e.g. based on other analyses, plans, or judgements.)

[5] The base year, 1988, was selected, as the most recent year for which extensive data for many sectors are available. These data were standardized to the official 1988 balance sheet as developed for the government of Senegal by ENDA.

END-USE BREAKDOWN USED FOR SENEGAL LEAP DEMAND MODEL



LEAP TRANSFORMATION MODEL FOR SENEGAL ENERGY SYSTEM



Future industrial energy use is assumed to increase with value added or physical production by subsector, with no attempt to reflect likely equipment changes and fuel switching. Limited data precludes much disaggregation of energy use patterns for other sectors; future energy use is assumed to increase with value added by sector.[6] Future research and analysis should be oriented towards improved understanding of energy use in the service sector and in the transport sector, which accounts for over half of final consumption of commercial fuels. (e.g., distances travelled, for what purpose, at what vehicle efficiencies, and barriers and opportunities to improved efficiency, mass transit, etc.) This in turn will enable consideration of other important factors and technolgy and policy options within the model. Due to the lack of reliable elasticities, price relationships (i.e. production functions) were not included in the current model, but could be in future iterations.

The structure of the "transformation model" depicted below is designed to represent, in a simplified manner, the operation of each of Senegal's major "energy industries". Self-generators of electricity are assumed to continue production with no changes, unless industrial development plans indicate otherwise. A module representing SENELEC, the parastatal electric utility, provides the remainder of electricity demand, with grid-connected facilities dispatched according to an annualized load curve, and isolated facilities operating separately to meet additional rural demands. Separate modules were created for charcoal, crude oil and natural gas production, with additional modules available for peat and lignite production, which are not considered in the scenarios here.

5. Preliminary Scenarios

5.1 Reference Case

A simplified reference case has been developed as a background for the analysis of policy scenarios, using a time horizon of 2005. Assumptions regarding demographic and economic growth are drawn from indicative estimates developed by a diverse team of researchers and managers contributing to the government's "Plan D'Orientation 1989-1995". They reflect continued rapid urbanization (to a 2015 population of 16 million, 9 million urban), and growth rates for individual economic subsectors that range from over 3 percent/year for fishing, services, and other industries to 2 percent/year for extractive industries (phosphates and salt) to no growth in the troubled vegetable oil industry. In addition, the saturation of household electrical appliances was assumed to nearly double during the 17 year time period considered here. Although other energy use patterns are likely to evolve in the future in the absence of new policy initiatives, such as changes in fuel choice or reduction in cooking energy with the adoption of quicker-cooking foods, these have yet to be reflected in this reference case.

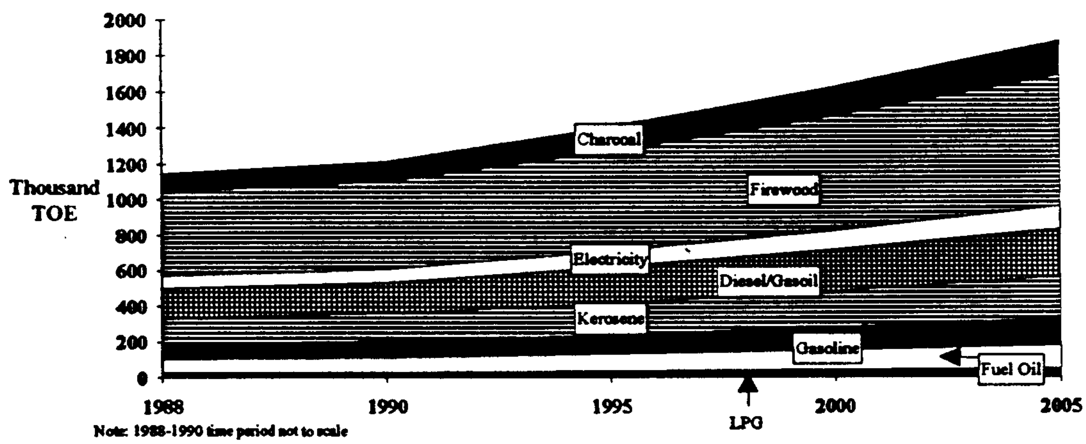
---

[6] Industrial audits conducted as part of the industrial energy conservation project will be used in the next phase to provide greater ability to estimate future use and represent policy options.

The reference case includes all electric plant additions and retirements specified in the SENELEC reference plan from August 1989.[7] This comprises the replacement of older oil fired capacity with new higher efficiency fuel oil and diesel base load and peaking stations. The reference case also assumes continued operation of the national refinery and no new penetration of improved biomass kilns, stoves, or other efficient end-use equipment.

Selected energy results of the reference case are shown below. From 1988 to 2005, total final energy consumption grows steadily at a pace of 3 percent per year, while primary energy increases somewhat more slowly at 2.6 percent per year. This difference is primarily due to the improvement of electric sector thermal efficiency from a system average of 27 percent to 38 percent, as older, inefficient generating units are replaced. Among end-use fuels, electricity, charcoal, and LPG consumption grow fastest (3.5-3.6% average annual growth), while firewood consumption grows slowest (2.6%), reflecting the overall effects of increased urbanization.

Final Energy Consumption, 1988-2005
Reference Case

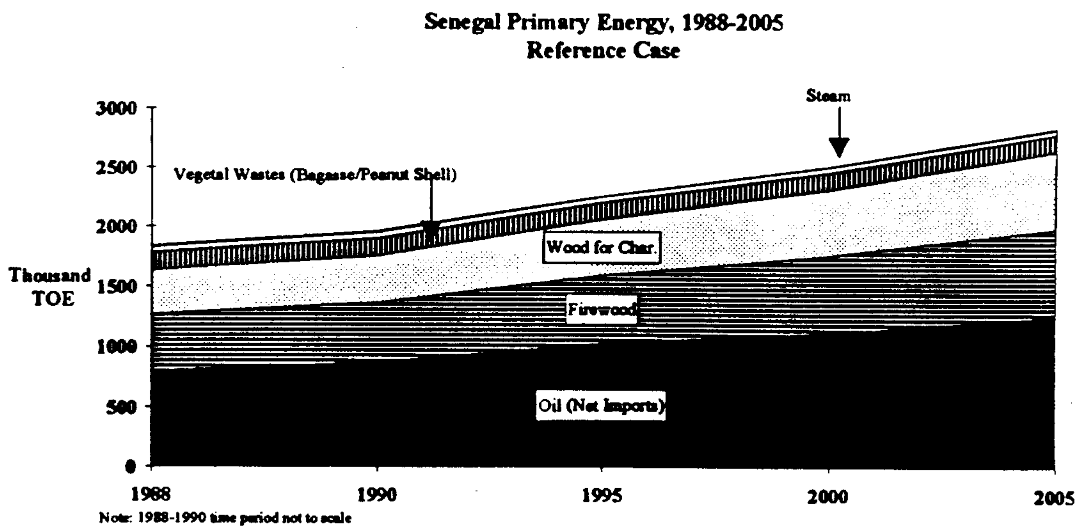


In terms of primary energy, overall oil imports increase by 56 percent from 1988 to 2005, and wood requirements for charcoal production increase by 80 percent, to over 2.3 million cubic meters per year, approaching earlier estimates of available wood productivity for the entire country. Not surprisingly, the reference case presents continued burdens on both national accounts and natural resources.[8]

---

[7] "Programme D'Equipement de Production sur le Reseau Interconnecte a Moyen et Long Terme", Direction des Etudes Generales, SENELEC, August, 1989.

[8] A more detailed analysis is underway using the LEAP Biomass program to better estimate available wood supplies on a regional basis, and to assess whether the projected urban and rural demands can be satisfied, with or without significant, unsustainable cutting of wood stocks (e.g deforestation).



5.2 Four Preliminary Policy Scenarios

Four very preliminary scenarios are presented here against the backdrop of the reference case. Each scenario builds upon the elements of the previous. Scenario A, *butanization* , considers continue promotion of an urban transition from charcoal/wood to LPG (i.e. butane) cooking. Scenario B, *improved biomass efficiency,* looks at improved stoves and kilns, amid the butanization strategy of Scenario A. Scenario C adds to this *improved commercial energy efficiency* for electricity and fossil fuel end-uses, while Scenario D, hydro, considers the additional effects of successful completion of plans to jointly develop hydroelectric resources with neighboring countries.

The order of the scenarios is based on judgement by study participants of both the likelihood that each policy could be achieved in practice and their relative costs. Further analysis will be conducted to review these assumptions, by looking at the actual costs and benefits of these strategies and further assessment of policy prospects. This may in turn result in a new set of scenarios. Nonetheless the scenarios presented here shed light on the interactive effects of combined policies, and simulate the procedure to be used for testing a wider range of scenarios in Phase II of this project.

We designed the preliminary scenarios to address possible policy options for addressing the major energy and environmental issues facing Senegal: oil import dependence and biomass use. Ironically, the first scenario appears to worsen the first problem to improve the second; presenting an interesting tradeoff among competing policy goals. The butanization and improved biomass efficiency scenarios could have potentially positive impacts in terms of land degradation, local and global climate change, and indoor air pollution. As noted above, Senegal may be particularly sensitive to the impacts to climate change, and has already experienced significant deterioration of local ecosystems and land productivity. Butanization, may or may not have positive impacts in terms of all impacts, depending on a number of assumptions, particularly regarding the renewable nature of the biomass fuel (mostly charcoal) that LPG would displace.

The scenario encompassing improved efficiency of modern fuels provides obvious benefits that would accrue from reduced fuel consumption: lower greenhouse gas emissions, improved urban air quality, and improved local air quality surrounding electric and other major fuel burning facilities. Finally, the hydroelectric scenario provides a tradeoff among impacts and their location.

Scenario A: "Butanization"

Rather than assume 1:1 useful energy substitution of LPG for charcoal (and wood), we base future cooking energy use on current observed patterns of mixed fuel usage to reflect actual experience of households that have switched to LPG.[9] Recent urban surveys have dissaggregated households into the categories of increasing transition to cleaner, more convenient fuels: wood alone, charcoal alone, charcoal with gas, gas with charcoal, and gas alone. Here, we assume a transition to the average characteristics of "gas with charcoal" cooking in those major urban areas with already substantial levels of LPG use (Dakar, Thies, St. Louis) by the year 2000, while in other urban areas the transition occurs more slowly. The "gas with charcoal" category still maintains considerable charcoal use: LPG/charcoal mix is a approximately 50/50 on a final energy basis. Only by the year 2005, do we assume the predominance of LPG cooking (90 percent of cooking fuel), and only for these three cities. Although such a transition may appear somewhat unrealistic, at the rate of subsititution suggested by preliminary analysis of 1989 surveys, this transition could occur even more rapidly. Whether continued subsidies would need to continue at the current rate for this transition to occur is not clear. Increasing the charcoal price could achieve the same goal, but perhaps at greater hardship to poorer urban dwellers, and with significant political obstacles to its implementation.

Scenario B: Improved Biomass Efficiency

The many efforts to date to develop and disseminate improved stoves and charcoal kilns have met with considerable difficulty and limited success. (see Diour, 1991; Ribot, 1990; World Bank, 1989) Therefore we have developed very conservative estimates of achievable potential (15% penetration of charcoal stoves that save, on average, 40%, leading to a savings of only 6% by 2005; 20% penetration of improved charcoal making, leading to further savings of about 6%). The small level of these savings is further reduced by the shift away from charcoal to LPG; there are simply fewer old charcoal stoves and kilns to replace.

The scenario design should not be interpreted as a dismissal of improved stove efforts. Effective stove programs have been implemented in several countries (e.g. Kenya, Tanzania), and a project is now underway to introduce an adapted Kenyan

---

[9] Although this approach has certain advantages, it potentially obscures the implicit differences in income and lifestyle among groups in different fuel categories. It could be that households currently using "gas with charcoal" have different cooking and eating patterns than households using charcoal alone, as a function of disposable income and status (changes in which are arguably much hard to implement than a butanization policy).

"jiko" stove in Senegal. Additional scenarios might seek to be as optimistic for improved stove penetration as the current set are for butanization.

Scenario C: Improved Electricity/Fossil Fuel End-Use Efficiency

Based on some broad initial estimates, this scenario is designed to reflect the potential of cost-effective demand-side efficiency improvements to reduce overall energy costs, and, at the same time, to reduce emissions and environmental impacts associated with the avoided energy use.

Senegal has been the site of one of the most intensive industrial efficiency projects in Africa to date. Industrial establishments comprising over 60 percent of industrial sector energy use were audited, indicating a potential for cost-effective savings of approximately 14 percent. Many of the low initial cost measures have or are planned to be implemented; these savings should thus be included within the reference case. In an approximation of possible savings, we reflect these savings results in an assumption that between 1988 and 1995, end-use efficiency improves by 10 percent, after which it improves at a rate of 1 percent per year (with continued technological progress and opportunities afforded by turnover of capital stock etc.). The relatively low level of industrial efficiency improvement potential compared with other studies for other regions reflects the role of current very high energy prices in Senegal (and the relatively high price elasticity of industrial sector energy use).[10]

For other sectors, there are few locally available estimates of cost-effective energy savings potential, so we draw temporary, indicative assumptions from studies in other regions. For instance in the services sector, where GDP is projected to grow at over 3 percent per year in Senegal, commercial building studies in other tropical countries have shown substantial potential for savings, particularly with improved lighting and cooling technologies. Based upon our review of the literature, as illustrated in the adjoining text box, we estimate that service sector energy efficiency could potentially improve at an annual rate of 2.5 percent. For transportation, given the lack of local data on energy use patterns, we rely on rough estimates based on assumptions for efficiency improvement potential for all developing countries from a recent report on the transportation sector.[11] Due to time and data limitations, additional efforts to improve supply-side efficiencies have not yet been considered.

---

[10] See Lazarus,M., Greber, L., and Hall, J,. et al. 1992. "Towards Global Energy Security", SEI/Greenpeace International, for documentation of studies showing higher industrial efficiency potentials.

[11] Based on analysis by Michael Walsh, currently in draft form. His analysis shows the potential for approximately 2%/year improvement with ambitious policies. We use this rate for road transport only, and do not assume any improved efficiency for air, water, or rail.

Commercial Building Energy Savings

In warmer regions, service sector energy use tends to favor electricity, as cooling and lighting tend to be the big energy users. In Sao Paulo, Brazil's largest city, approximately 44 percent of service sector electricity use provides lighting, while air conditioning (20 percent), refrigeration (17 percent), and cooking (8 percent) account for most of the remainder (Geller, 1991b). In Thailand, lighting accounts for 31 percent of total service sector energy use (Busch, 1990).

More efficient lighting generates less heat, and can result in significant additional benefits in terms of reduced cooling loads. Not surprisingly, this phenomenon is most marked in hotter climates. In Thai office, hotel, and retail buildings, lighting improvements can reduce lighting energy use by 70 percent, while at the same time reducing energy needs for cooling (12 to 33 percent, depending on building type), and ventilation (13 to 26 percent) (Busch et al., 1991). The estimated costs of saved energy for these measures are all at or below $.04/kWh (1991 U.S.$).

Analysis of energy end uses in Thai commercial buildings found that efficiency measures could cut electricity and on-peak usage, and resulting electricity bills, in half. All of these measures were found to be cost-effective, based on a tariff of $.05/kWh, $9.16/kW (Busch, 1990). Using a detailed electric utility financial model, investments in conservation were shown to be 75 percent less capital intensive than avoided electric capacity investments (Busch, 1990).

Designing commercial buildings to accommodate local needs and preferences in developing countries can also help reduce energy use. For instance, Thai buildings are typically designed to meet American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) standards, which are based on comfort levels acceptable to a white, male, college age population (Busch, 1990). In contrast, Thais consider higher indoor temperatures and humidity levels to be acceptable, and are comfortable 4 degrees Centigrade above the ASHRAE standard (Busch, 1990). Clothing is an important factor; not surprisingly, adopting Western-style dress -- business suit and tie -- can require greater levels of air conditioning.

While increasing use of computers, faxes, and other office equipment could increase electricity use and cooling loads (due to the heat that they generate), efficiency improvements could well offset such increases. As part of their U.S. study, OTA found electronic office equipment could be 80 percent more efficient than current models, based on reduced idle time and improved technology.

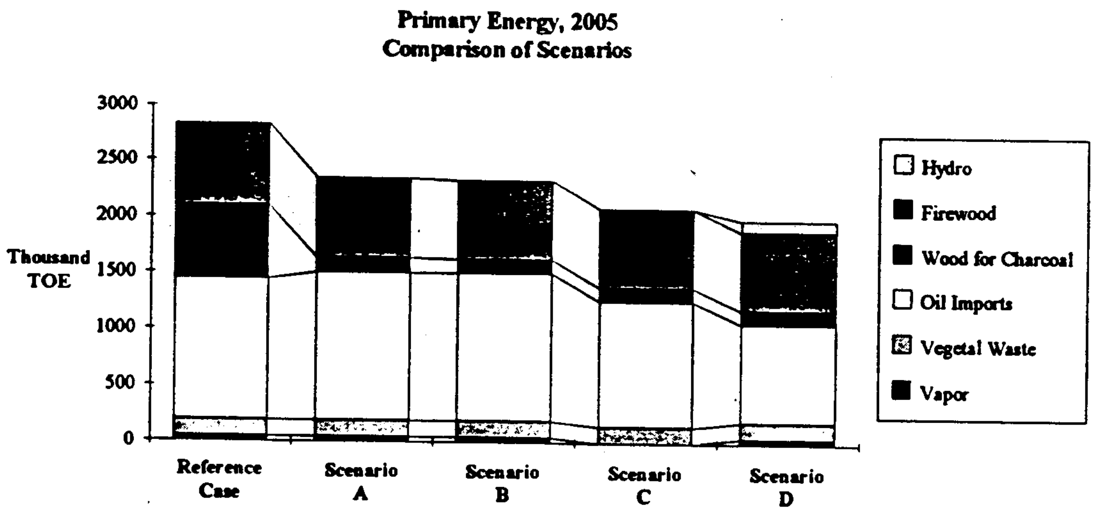
Service Sector Efficiency Improvement Potentials

Country/Region	End-Use	Energy Source	Savings vs. Current Stock	By Year	Annual Savings*	Source/Notes
Brazil	Lighting	Electric	60%	2010	4.1%	(Geller, 1991)
Brazil	A/C	Electric	40%	2010	2.3%	(Geller, 1991)
OECD	All	Fuel	55%	2010	3.6%	(Schipper&Meyers, 1992)
OECD	All	Electric	65%	2010	4.7%	(Schipper&Meyers, 1992)
Thailand, Office	All	Electric	45%			(Busch, 1990)
Thailand, Hotel	All	Electric	51%			(Busch, 1990)
Thailand, Retail	All	Electric	56%			(Busch, 1990)

Scenario D: Hydroelectric additions

This scenario assumes the successful completion of projects to import hydropower from the first projects of the Senegal River Authority, the Manantali and Felou dams located in Mali. Although Senegal, Mauritania, and Mali, joint partners in the Authority, have already succeeded in jointly constructing the dams, political obstacles have prevented them from reaching a full cost/capacity sharing agreement, installing the over 200 MW of turbines, and building the long-distance transmission lines. Since the recent reopening of Senegal-Mauritania border, inter-country negotiations appear close to resolution, and there are strong indications that the hydroelectric potential could soon be tapped. However, the high cost of the long high-voltage transmission line to the main load centers in coastal Senegal must be balanced against the costs and benefits of alternative strategies. For this scenario we adopt previous SENELEC study assumptions that Senegal's capacity share will be 45 percent, and that 90 MW will be available in 1996 (Manantali) and 47 MW in 1998 (Felou). In the subsequent phase, cost-benefit analysis for this and other scenarios will be added.

Scenario Energy Results



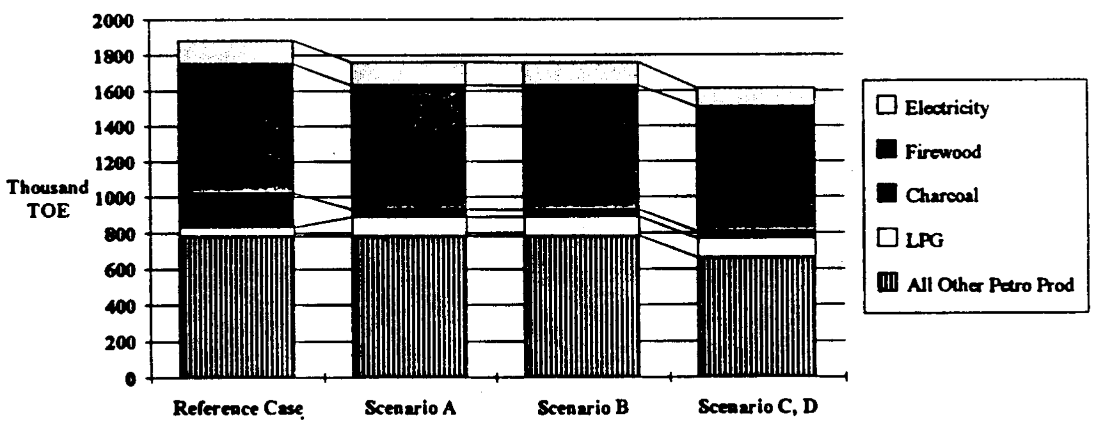
Each successive scenario reduces future national primary energy requirements, as shown above. The results are most marked for Scenario A (Butanization) and Scenario C (Improved Commercial Energy Efficiency), as shown below for the year 2005. Relative to the reference case in 2005, the butanization scenario reduces total wood requirements for charcoal production by almost 80 percent, while increasing LPG consumption by 115 percent, or about 4.6 percent per year. Relative to 1988 levels, wood requirements for charcoal production decline almost 70 percent, from over 900,000 tonnes in 1988 to 300,000 tonnes in 2005. Urban firewood use declines from about 17,000 tonnes in 1988 to less than 2,000 tonnes in 2005. Since cooking energy requirements, on a *useful energy basis*, are a relatively small part of the total energy required nationally, total national oil imports increase by less than 5 percent (from 1.25

to 1.31 million TOE), relative to the reference case in 2005. Significant reductions in total primary energy requirements are achieved (from 2.83 to 2.34 million TOE) as the substantial losses due to inefficient charcoal production and use are greatly reduced.

Scenario B, with more efficient charcoal kilns and stoves could also reduce these losses. However due to two factors, very conservative assumed penetration rates and the decreased losses already achieved by switching to LPG, the impact of Scenario B appears very small.

With the achievement of improved efficiency potentials in most demand sectors, combined with butanization, by 2005, Scenario C achieves significant decreases in final consumption of nearly every fuel compared with the reference case: electricity (19%), all petroleum products including LPG (8%), charcoal (80%) and firewood (4%). When translated into primary energy, the reduction in fuel requirements for power generation leads to a total reduction in oil requirements of 12 percent, relative to the reference case in 2005. Oil consumption for 2005 decrease by 31 percent in Scenario D, with the displacement of oil-fired generation by 130 MW of new hydroelectric capacity.[12]

Final Energy Consumption, 2005
Comparison of Scenarios



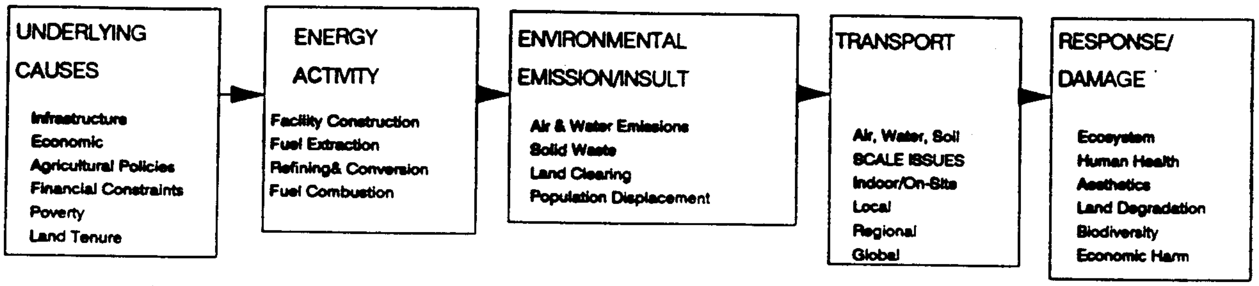
These results, though not finalized, are indicative of potential savings in both oil and charcoal consumption that might accrue from a combined strategy of butanization, improved efficiency, and hydro development. The next section presents an approach to assessing some of the environmental benefits and costs associated with these scenarios. As a next step in deepening the energy sector analysis, cost-benefit comparisons will be developed, and as noted in the foregoing text, many aspects of these scenarios will need to be revisited. Finally, the political feasibility and operational effectiveness of policy mechanisms available to Senegalese officials to achieve these strategies will need to be addressed, and through discussions with study participants, a revised set of scenarios defined.

12 By 2005, hydro facilities provide 78% of total national electric generation in Scenario D.

6. Environmental Analysis

The environmental impacts of energy options have been studied extensively over the past two decades. The scientific literature abounds with approaches to the analysis of the social, health, and ecological effects of various energy technologies. (See Ehrlich, Ehrlich, and Holdren, 1977; World Health Organization, 1989; Asian Development Bank, 1990) The diagram below represents many of the dimensions of these complex and interelated issues.

PATHWAYS FROM ENERGY TO ENVIRONMENTAL IMPACTS



As we focus here upon the linkage between energy activities and environmental emissions and insults, it is important to stress the relevance of other aspects to developing effective environmental strategies. Underlying dynamics and causal factors related to development and socio-economic relations can either foster or undermine otherwise well-intended policies (e.g. witness the difficulty of reforestation and wood energy plantation efforts). Transport of emissions can lead to trans-boundary problems such as acid precipitation and global warming, that cannot be resolved solely on a national level. There are also issues of air emission transport in urban areas, and broader issues of who benefits and who loses with environmentally damaging activities. It has been said that woodfuel issues cast an urban shadow over rural areas that bear the brunt of the impacts, with often few rural residents who benefit from this resource extraction. (A similar argument can be made about global warming, with current North-South patterns of fossil fuel use.) Finally, precise estimation of damages and impacts generally proves very difficult: the woodfuel-deforestation or greenhouse gas-global warming-economic damages relationships are prime examples.

Despite obvious complexities and uncertainties related to many energy-environment issues, *comparative, quantitative*, environmental analysis of energy scenarios can provide insights towards achieving least cost strategies. While incomplete, such an approach begins to bring environmental questions into the overall planning framework, and raises questions which might otherwise be absent from the policy debate. While simplifying the complex web of human and environmental interactions, this study seeks to elaborate an approach that can be implemented within the time, data, and institutional constraints that are faced by planners in the African context.[1]

[1] For a discussion of the models and approaches for looking at some of the other aspects of the system, e.g. transport-impact models, etc., see also WHO (1989), ADB (1990), and World Bank (1991). The approach described here is not intended to substitute for, rather to stimulate, more thorough project-specific environmental analysis, such as that typically undertaken in an Environment Impact Assessment.

The two greatest difficulties in a quantitative approach are the integration of factors that are impossible or difficult to measure (e.g. ecological damage, soil degradation, aesthetic impact), and the comparison across seemingly incommensurate impact categories (e.g. balancing human health, ecological, or economic costs and benefits). Section 7 touches briefly on some possible ways to address these issues.

6.1 Environmental Data Coverage

EDB

The emphasis of the combined LEAP/Environmental Database (EDB) framework is to provide a means for rapid initial assessment of the comparative impacts of energy policies. As such, EDB provides a comprehensive database of environmental impacts associated with energy use. It contains a large existing database of coefficients describing air, water, solid waste, and occupational health and safety effects. This core data of EDB are derived from 70 literature sources of international origin.

Using EDB, and the original primary data sources, a set of emission factors were developed and tailored to the Senegal and regional African context. It must be emphasized that none of the emission factors were derived from tests or measurements conducted in Africa, of which there appear to be few to date. Instead, they were derived from the relatively limited number of studies to date, most based on measurements in and for OECD countries, most notably the US. In fact, most emission factors for fossil fuel combustion can be traced to a handful of studies conducted in the U.S. in the 1980s. For transport and household sectors, as described below, emission factors were also drawn from Asia, which shares with Africa, an older less maintained vehicle stock and the use of small household stoves, often with traditional biomass fuels.

Since LEAP can be used to cover most aspects of the fuel cycle (and will soon be expanded for full fuel cycle analysis), environmental emissions can be tracked from resource extraction to final use. When comparing energy options, it is important to consider environmental impacts beyond those of fuel production and use, to the "upstream" and "downstream" effects. For instance, an environmental analysis of electrification should consider not only the impacts of fuel use for electric generation and transmission/distribution impacts, but the host of resource production impacts: oil production, oil spills, coal/peat mining, etc. Important elements of the fuel cycle include: Exploration ⇒ Extraction/Production ⇒ Storage ⇒ Transport ⇒ Fuel Processing ⇒ Fuel Conversion ⇒ Distribution ⇒ Utilization ⇒ Disposal.

Emission source categories were created for most aspects of energy production and use in Senegal, in an attempt to maximize coverage of the full fuel cycle, leaving aside some of the issues most difficult to assess (spills, disposal, and many of the rural effects of woodfuel extraction). These emission factors were then linked within LEAP to the appropriate energy demand and supply activities, to yield the environmental loadings associated with each of our scenarios. These categories can be illustrated in reference to the Senegal energy balance (ENDA, 1990), in a similar fashion to that used in a previous study for Senegal (Amous, 1992), as depicted below.[2]

[2] Major differences with the previous study, a current emissions assessment, include revised, technology/device specific emission factors and coverage of non-greenhouse gas emissions.

APPLYING EMISSION FACTORS TO THE SENEGAL ENERGY SYSTEM

	Crude Oil	Gasoline	Kerosene Jet Fuel	Diesel	Fuel Oil	LPG	Nat. Gas	Peat/ Coal	Veg. Waste	Fire Wood	Ch Co
PRIMARY PRODUCTION											
Crude Oil Production	■										
Natural Gas Production							■				
Peat Production								■			
TRANSFORMATION											
Electric Capacity (by type)				■	■		■	■	■		
Refinery	■										
Charcoal Making											■
Transmission/ Distribution Losses		■	■	■	■	■	■				
FINAL CONSUMPTION											
INDUSTRY											
All Industry				■	■						
FISHING											
Traditional		■		■							
Modern		■		■							
TRANSPORT											
Car		■		■							
Heavy Road		■		■							
Rail				■							
Air		■	■								
HOUSEHOLD/OTHER											
HH Cooking/Heating			■	■		■			■	■	■
Other HH End Uses			■			■					
Comm/Service Bldgs				■		■					

With the exception of the carbon dioxide emission factors, we have developed emission factors that lie within the range of available data, as consistent as possible with other factors from the same source, and with a notion of the types of equipment currently in use in Senegal. The derivation of these factors and some of the major issues related to them are discussed below.

Emission/impact categories considered in Phase I

Coefficients for items such as soil erosion, land use, direct health and safety, solid waste and water effluent emissions from energy processes were reviewed, but given the paucity and incompleteness of available data, were not included in this phase of the analysis for Senegal. At this stage, the following 9 categories are included: carbon dioxide (CO_2) from fossil fuels, net biogenic CO_2 from biomass fuels, carbon monoxide (CO), methane (CH_4), other volatile hydrocarbons (HC or VOCs), nitrogen oxide (NO_x), nitrous oxide (N_2O), sulfur oxides (SOx), and total suspended particulates (TSP). These categories are described briefly below.

Carbon dioxide (CO_2), the major greenhouse gas both in terms of quantity emitted and overall effect on global warming, is released whenever a fuel that contains carbon is combusted, or oxidized. It is released in quantities generally proportional to the carbon content of the fuel; the development of CO2 emission factors is described in Annex 3. CO2 emissions from fossil and biomass fuels are treated separately.

Non-biogenic ("fossil fuel") CO_2. Non-biogenic emissions are those derived from combustion of fossil fuels and other sources of carbon dioxide (e.g. geothermal wells) for which the carbon emitted is either of geological origin or, as is the case with coal, oil, gas, and peat, was formed from biological material but on geological time scales, that is, so long ago that the fuels are essentially non-renewable. Non-biogenic emissions constitute a net addition of CO_2 to the atmospheric pool of the gas, at least on a human time scale.

Net Biogenic CO_2. Biogenic emissions, in contrast, result from biomass combustion, and do not constitute net additions of CO_2 to the atmosphere, *under conditions of sustainable biomass harvesting*. Under these conditions, the CO_2 released upon combustion of biomass-derived fuels can be recaptured during photosynthesis in the next biomass growth cycle.[3] Non-sustainable harvesting of *biomass*, leading to soil and land degradation, and in extreme cases, to deforestation and desertification will cause net additions of CO_2. We discuss the relationship between biomass energy use, deforestation, and net CO_2 emissions in Senegal in the next section. Since net CO_2 emission estimates are developed based on the estimated relationship, it provides a *useful indicator variable for energy-related deforestation and land degradation*.

For carbon dioxide, the principal methods of reducing non-biogenic emissions are to use fossil fuels more efficiently, switch to fuels that produce less CO_2 per unit energy (coal to natural gas), switch to renewable fuels, or, preferably, a combination of these techniques. While there are technologies under development for capturing CO_2 from the exhaust gases of combustion equipment or for pre-processing fuels to remove carbon, these technologies are not considered here, since they are too remote and expensive for near term application in Senegal. Reducing net biogenic CO_2 emissions can also involve improving biomass end-use efficiency, charcoal production efficiency, or modifying harvesting and forest management practices.

Incomplete combustion products

Under ideal conditions of complete combustion, the hydrocarbon fuels, fossil and biomass, would yield only CO2 and water, with additional particulate and trace emissions based on fuel contaminants (e.g. sulfur) or additives (e.g. lead). However, under normal conditions, incomplete combustion occurs, producing emissions of CO, NOx, N2O, CH4, and HCs, which are described below. As with carbon dioxide, emissions of incomplete combustion products per unit energy services provided can be reduced through efficiency improvements and fuel-switching. In addition, emissions of these gases from existing equipment can be reduced by optimizing combustion conditions and by proper maintenance of fuel consuming

---

[3] For example, if a hectare of corn were grown to produce 3,000 liters of ethanol, and the ethanol was then used as fuel, there would be a temporary addition of CO_2 to the atmosphere, but the next year, planting the same hectare of corn would reclaim a similar quantity of carbon dioxide from the atmospheric pool. The key here is that biogenic emissions of CO_2 can result in no net addition of CO_2 to the atmosphere, and no net loss of carbon from the terrestrial biomass.

devices. For example, older automobiles on average typically produce much higher emissions of CO and HC per mile as they age, partially due to maintenance. In addition, new equipment can be designed so as to both burn the fuel more cleanly and to trap pollutants, via various types of control equipment, before they reach the atmosphere. As an example of the effectiveness of these measures, emissions of CO and HC from new U.S. cars are roughly 10-fold lower than for 20-year-old cars in the U.S. fleet.

Carbon monoxide (CO) is a local air pollutant, with respiratory impacts, and contributes both directly (as it oxidixes to CO2) and indirectly to the increase in greenhouse gas concentrations in the atmosphere. Emissions of carbon monoxide are primarily a function of combustion conditions; inefficient combustion generally increases CO emissions. Vehicles tend to be the major source of CO emissions in most areas. Carbon monoxide is created in oxygen-starved, fuel-rich combustion conditions, such as by low speed and idling vehicles in congested urban areas.

Methane (CH_4) is a powerful greenhouse gas, emitted as a by-product of fuel combustion, through leakage from natural gas, oil and coal extraction, transmission, and distribution facilities, and from other agricultural and natural (non-anthropogenic) sources. Methane contributes directly to warming and also interacts with both tropospheric ozone and stratospheric water vapor, thus enhancing its overall contribution to global warming.

Hydrocarbons (HC, VOCs), contribute to photochemical smog and the production of ground level ozone, which is dangerous to human health due to respiratory system effects. High ozone levels also damage crops, forests, and wildlife. Separate from methane, they are likely indirect contributors to global warming.

Nitrogen oxides (NO_x) contribute to many air quality problems, with direct effects on human health, and contributions to particulate and ozone formation, acid precipitation, and, indirectly, it appears, to global warming. The nitrogen in nitrogen oxide combustion products is derived from nitrogen from various compounds in the fuel and from molecular nitrogen (N_2) in the air. Higher combustion temperatures (which generally promote more complete combustion) tend to increase NO_x formation, as more N_2 from the air is oxidized. Several technologies exist that can reduce NO_x emissions from new and existing equipment. Some of these technologies act to reduce the amount of NO_x formed during combustion ('low-NO_x burners') by modifying combustion conditions, and others (e.g. Selective Catalytic Reduction for power plants) trap NO_x or convert it to other nitrogen compounds.

Nitrous oxide (N_2O) is a very powerful greenhouse gas (on a weight basis), but quantities emitted are subject to large uncertainty. Its process of formation still poorly understood.

Trace Contamintants

Sulfur Oxides (SOx) can lead to respiratory impacts and acid rain. Emissions are generally proportional to trace contamination of sulfur in fuels derived from coal, crude oil, and other resources. Sulfur emissions can be controlled using desulfurization equipment (scrubbers) on powers plants and other large point sources, and through fuel processing (e.g. coal washing).

Particulates (TSP) can result in impacts on respiratory systems, visibility, and other aspects of human welfare. Particulate emissions are emitted during combustion, as a function of non-combustible fuel contaminants such as ash content.

Lead (Pb) emissions can lead to blood poisoning. Lead additives to gasoline are largely responsible for lead emissions.

6.2 Development of Energy-Environment Coefficients

The uncertainties associated with the emission factors used here vary greatly among the different species. Estimates of fossil fuel CO_2 emission factors are primarily dependent on fuel carbon content, and thus usually have relatively little variability, particularly for petroleum products and natural gas. Carbon dioxide emission factors can probably be considered accurate to within 5 percent. Other emission factors are typically based on the results of a relatively small number of tests of fuel use in particular types of equipment, so in order to ascribe emission factors to specific sectors or subsectors of the energy economy it is necessary to judiciously make a number of sweeping assumptions. As a result, it is difficult to assign an uncertainty to these emission factor estimates. Increased emissions testing in both the developing and industrialized world, with centralized international reporting of results, could help greatly in reducing these uncertainties. Issues regarding impacts and coefficient development are described by sector below.

Household Sector

According to the recent study described above (Amous, 1992), the household sector could account for over 40% of energy-related greenhouse gas emissions in Senegal. Demand for biomass fuels could also be a significant contributor to problems of deforestation, soil erosion, and ecosystem damage. In addition the extensive use of traditional cooking fuels and equipment, may pose considerable health risks, particularly to women. For example, very high concentrations of carbon monoxide (940 ppm) have been reported for households in Lagos, Nigeria. (Smith et al, 1983, as reported in Adegbulugbe, 1992).

Biomass energy use, deforestation and net CO_2 emissions

The role of biomass fuel consumption deforestation, soil erosion, and land degradation and in terms of greenhouse gas emissions remains highly site specific. Does biomass energy use pose serious environmental consequences in a developing country such as Senegal? While many studies and observers are often quick to say yes, the answer is not necessarily evident. For many African countries, simple calculations were made in the 70s and early 80s showing that demand for firewood and charcoal in excess of estimated annual growth would lead to deforestation, and eventually to supply "gaps" and the total harvest of available wood. The specter of massive deforestation and resulting desertification of semi-arid regions was raised, and has since been hotly debated. It has become increasingly clear that in most cases the primary direct causes of deforestation and land degradation are the expansion of cultivated areas, overgrazing, and, in some areas, logging for commercial wood exports, with underlying causes such as lack of land tenure, expanding population, and low agricultural productivity. In many cases woodfuel supplies may be derived from land clearing, but it is not these demands, but rather the need for agricultural and grazing land by increasing and/or marginalized populations that cause the land clearing in the first place. So does continuing reliance on simple biomass fuels lead to deforestation and land degradation? Where would cooking and heating fuels come from if this land clearing were not to occur? And how do these dynamics change with expanding population densities?

With myriad local factors affecting patterns of land use and biomass energy use (wood cutting technologies, local custom and cooking preferences, costs and availability of alternative fuels, geographic/ecological/climatic constraints, etc.), global answers to these questions are difficult. At the same time, these issues are critically important. Arguably, the most important environmental issues in Senegal today are those related to the loss of natural forests, soil erosion, and overall land degradation. In addition, concern over the impact of land clearing and biomass combustion on greenhouse gas emissions has once again motivated international donor agencies and research institutions to turn their attention to these issues.

Recognizing the complexity of the problem, it is nonetheless important to make some broad estimates of the impact of biomass energy use on the environment if we are to inform decisions of resource use. To inform estimates for this study, we briefly review some assumptions from recent studies for Senegal and other countries.

Globally, it has been estimated that biomass energy use causes one-eighth of observed global deforestation; the rest due to logging, land clearing, and road building. (Ahuja 1990, as cited in Smith et al, 1992). For Brazil, Poole and Moreira (1992) suggest that for firewood, residential and agricultural uses do not contribute significantly to deforestation. "Relatively dispersed use in rural areas does not exceed natural regeneration...Some deforestation nevertheless occurs..It is assumed that 20% of these sectors' fuelwood results in net CO2 emissions." For industrial fuelwood use, they assume that 60 percent contributes to CO_2 emissions, while they assume that 50% of total charcoal production leads to deforestation and net CO_2 emissions.[4]

Such estimates are obviously imprecise, and should be viewed with high uncertainty. For Senegal, a few estimates have been made of land clearing attributable to various causes, as shown below.[5]

Land Clearing Estimates for Senegal

Total Forest Clearing (Hectares/Year)	% of Natural Land Area*	Attributable to:	Source
165,000	1.1%	All Causes	(World Bank, 1983)
200,000	1.3%	All Causes	(Senegal government, 1984 as cited in Ribot, 1990)
60,000	0.4%	Agricultural Clearing	(Republique du Senegal, 1992)
12-22,000	0.1-0.2%	Charcoal production	(Ribot, 1990)
50,000	0.3%	All Woodfuels	(Senegal national report, cited in Environnement ..., 1991)
50,000	0.3%	Charcoal Production	(Amous, 1992)

* - Including steppe (3,200,000 ha), dry savanna (4,400,000 ha), wooded savanna (6,700,000 ha), and forest (400,000 ha).

4 They assume that 2/3 of charcoal comes from natural forests and 3/4 of this production leads to deforestation – the other 1/4 coming from land clearing for agriculture and/or grazing.

5 Without continuous land mapping, these estimates tend to extrapolate from assessments done many years apart that have used somewhat incompatible methods (e.g. different land type categories), thus are subject to significant uncertainty.

Land clearing alone does not necessarily imply permanent deforestation. Under certain conditions -- adequate soil moisture, limited soil erosion, presence of seeds or coppices, and limited land pressures (grazing, brush fires, continued wood harvesting), for example -- forest can regenenerate within 1 to 2 human generations. A review of studies of forests previously cleared for woodfuel production in Senegal and Nigeria suggests a range of impacts under actual conditions, but are inconclusive for precise or generalized determination. (Ribot, 1990) Biodiversity appears to be reduced.

Measured forest impact is only part of the environmental picture. Villagers experience the impact of charcoal production most strongly. A survey of village women found that half blamed charcoal producers for wood scarcity, while they cited the dissappearance of game species, destruction of fodder, water conflicts, and social problems as other reasons why well over half would prefer to see the charcoal makers leave their forests. [6] (Ribot, 1990) Some researchers have found that in areas where charcoal production takes place, largely to meet urban demands, villagers experience fuelwood scarcity that was not present before, or is not found in other villages where charcoal makers are absent.

Stopping charcoal production in Senegal will certainly not halt deforestation, and the full extent of the ecological damages of this industry are not fully understood. Nonetheless, according one study, "charcoal is a key cause in the decline of Senegal's ecology." (World Bank, 1989) Some impacts may be reversible, others not. In terms of the fraction of charcoal production that leads to permanent deforestation, an arbitrary figure of 50 percent may appear to be high in light of the uncertainties noted above, but low with respect to previous assumptions on this issue.[7] At an average productivity of 18 tonnes of wood per hectare, the estimated 900,000 tonnes of wood consumed for charcoal production in 1988, would correspond to approximately 25,000 hectares of deforested land per year, in the middle of the range of estimates above. (At higher wood productivities found in the current charcoal production region, Kolda, the calculated deforested land area would be considerably lower.) While it may overstate the permanent impacts of charcoal production, this assumption reflects a high concern for the other immediate impacts on rural well-being and reduced ecological diversity. If pressures of global and local climate change continue to mount, along with other land pressures, this assumption could indeed prove to be low.

Rural consumption of charcoal is relatively minor compared with firewood, which generally tends to be gathered as twigs and dead wood, rather than from live trees (World Bank, 1989; Ribot, 1990). In general, it would thus seem that the contribution of rural firewood consumption to deforestation and net carbon emissions is relatively small. For now, we assume that the net contribution is only 10%, a somewhat arbitrary estimate, that lies between the assumptions for Brazil (20%) and an assumption of no impact (0%), that would seem unlikely. With increasing population densities, however, the impact of rural firewood demands can increase; it is possible that over the time horizon of this study (to 2005), that this 10%

---

[6] Other problems related to the charcoal trade include selective cutting of commercially valuable lumber species, road damage from heavy vehicle use. (Ribot, 1990)

[7] Amous (1992) implicitly assumes 100%, as do other researchers and analysts in their qualitative discussion of charcoal production impacts.

assumption could prove overly conservative in terms of damages. As with the other biomass-deforestation assumptions, it should be the subject of future sensitivity analyses.

The impacts of urban firewood consumption are assumed to be the mean of rural firewood and urban charcoal demand, while the impacts of rural charcoal (which we assumed to be purchased from the same markets that supply urban dwellers) are identical to urban charcoal consumption.

For agricultural residues, it might be argued that energy uses might reduce total soil carbon relative to what it would otherwise be, if the residues were left to rot or beplowed under. However, if they were burned in the fields, as is sometimes the case, total greenhouse gas emissions would be even greater than they would be under controlled combustion conditions found in their current electricity generation applications. We thus assume no net CO_2 emissions from agricultural residue energy uses.

CO_2 coefficients for Senegal

Biomass Fuel	Percentage of harvested wood that results in net deforestation and CO_2 emissions	Net CO_2 Emissions	
		gCO_2/kg fuel	tonneCO_2/GJ
Rural Firewood	10%	142	10
Urban Firewood	30%	426	30
Charcoal	50%	4520[8]	140
Agricultural Residues	0%	0	0

Other household emissions

Ideally, local emission measurements for the commonly used stoves (Nopale, Blip, Malgache, Saakanal, etc.) under standard Senegalese cooking conditions would provide factors for use in this study. Given the lack of such measurements, the closest analogue is likely a rough average of existing data. As illustrated in Annex 4 below, several emission measurements have been made for Asian stoves. A recent study by Smith et al. (1992) indicates that previously unmeasured greenhouse gases emissions (CH4, N_2O, etc.) from various household biomass fuels, may be relatively high. Combining these estimates with other emission estimates for "generic stoves", we have established current "best guess" estimates, as indicated in Annex 4.

Transport/Fisheries Sectors

Transport sector emissions are a source of the increasing levels of air pollution in urban areas of Senegal, although perhaps less so than in regions. In Asian, Latin American, and OECD cities, motor vehicles generally account for about 90 percent of CO emissions, and often a large majority of HC and NOx emissions. (Faiz, 1991) While it accounts for 10 percent of global population, Sub-Saharan Africa has only 2 percent of approximately 470 million vehicles in the world. Few studies have looked transport emissions issue in the African context. While not yet approaching the problems found in major cities in Asia and Latin

[8] Calculated based on current estimate kiln efficiency of 17% wt basis (based on ENDA, 1990) and 1540g CO_2/kg wood input to charcoal kilns, and the 50% net deforestation assumption shown here.

America, urban air quality problems related to transport emissions (vs. household/industrial) are of increasing concern in many African cities. For example, high levels of CO and SO_2 have been measured in Ibadan City, Nigeria, and typical haze and eye iritation are indicative of high levels of photochemical smog on major transportation routes in Lagos. (Adegbulugbe, 1992) In addition, leaded gasoline poses health risks, particularly to small children who breathe the higher lead concentrations found at or near tailpipe heights

The transport sector in Senegal is rather unique in the dominance of air transport, which accounts for over 40 percent of energy use in this sector. Since Dakar acts as a hub for a major regional airline (Air Afrique), the transport data may seem a bit misleading. Airplanes are fueled in Senegal in part to meet the transport needs of other countries. Furthermore, the emissions from planes departing Dakar may occur thousands of kilometers away. However, the issue responsibility for international transport emission could be considered no different from emissions associated with production of other export products: crude oil, refined products, even consumer goods which can eventually pose disposal/waste problems in the country of final use.

.Transport sector emissions depend on a variety of factors: vehicle type and emission controls, fuel characteristics, maintenance level, fleet age, and driving conditions. It is thus very important to take these factors into account in deriving emission coefficients. Many published transport sector emission coefficients implicitly assume vehicle stock and characteristics similar to those found in industrialized regions. While these conditions are obviously not found in a country like Senegal, local data are generally unavailable. Furthermore, the data are often U.S.-based, reflecting substantially different vehicle stock and emission control regulations than found in many other regions.[9]

Some of the available data on vehicle emissions are shown in Annex 5 below, illustrating a wide range of emission factors. The table illustrates the dramatic reductions in emissions of several pollutants (CO, HC, and TSP) acheived in newer U.S. vehicles, due to emission reduction technologies (e.g. catalytic converters) resulting from U.S. regulations. In addition to age, maintenance, and evolution in engine design, contribute to the decline, factors which would tend to influence emissions in Senegal.

At present, we develop current best guess estimates for Senegal, by averaging the emission characteristics of 1985 European vehicles and those of average Indian vehicles to reflect maintenance and age characteristics more typical of a developing country.[10] For rail, water, and air transport, we use EDB data derived from U.S. EPA studies.

Industrial and Services Sectors

For fuel use in these sectors, generic U.S. type equipment without emission control deveices were selected to represent fuel consuming devices in Senegal. Data are not readily

---

9 In Senegal, as in most of Africa, very few American-manufacturer vehicles can be found on the road.

10 The Indian emissions data were collected and used as part of transport study for Delhi using LEAP/EDB. (Bose et al, 1992). If further refinements are sought for transport coefficients, the data on the recent vehicle stock in Senegal are available. Together with estimates on driving conditions and fuel efficiency, these data can be used with an estimation methodology developed by the European Community to develop more precise emission estimates. (COPERT/CORINNAIRE)

available to distinguish among actual equipment characteristics by subsector in Senegal. The emission factors for this sector are shown in Annex 6.

Energy Sector: Production, Transformation, and Losses

Existing EDB data were used for most of the processes and facilities in the energy sector. Data on charcoal kilns, particularly earthen type traditionally used in many tropical countries, are very difficult to obtain, and were derived from U.S. based data. Electric generation facilities were linked to emissions data based upon actual fuel and technology characteristics. Bagasse and peanut shell-based self-generation was assumed to have no net biogenic CO_2 emissions as noted in the discussion above regarding agricultural residues. Standard coefficients for hydro impacts (e.g. population displacement, river basin ecology) were not developed due to the highly their site-specific nature. Natural gas losses and production, crude oil production, and refinery operations were associated with emissions characteristics that are listed for energy sector categories in Annex 7.

6.3. Environmental Results

Together, these emission assumptions result in the national sectoral profile for 1988 shown in the table below. While further analysis might enable a better assessment of the impact of these emissions, particularly their spatially-dependent relationships to indoor and ambient urban concentrations, this table nonetheless provides a starting point for general comparison among sectors and emission categories.

The three major categories of net carbon dioxide emissions are oil-fired electric generation, transportation, and charcoal production, each accounting for over 20% of the national total. The biomass harvesting assumptions noted earlier have a significant effect on the results. If all wood were assumed to be unsustainably harvested, with no regeneration, the net biogenic CO_2 would be over 3½ times the 900,000 tonnes calculated here, greater than the contribution all fossil fuels. As calculated here, biomass contributes 27% of total carbon dioxide emissions, and 33% of total global warming potential, using IPCC 1992 100 year integration estimates.

Charcoal production, in addition to its other local environmental impacts, could produce over 70 percent of particulate (TSP) emissions, over 40 percent of methane (CH4), and over 60 percent of other hydrocarbon (HC) emissions. Because these emissions occur over a dispersed area, their contribution to air quality and effects on local climate or visibility (particulates) may be small, and they should be compared with emissions from other forms of rural biomass burning, such as brush and crop waste fires.

Household consumption of biomass fuels appears to be the largest energy-related contributor in Senegal to methane and carbon monoxide (CO) emissions, and the second major contributor to particulate and other hydrocarbon emissions after charcoal production. Particulate, carbon monoxide, and hydrocarbon emissions could thus provide a useful, if very generalized, indicator of indoor air quality issues.

1988 Emission Estimates by Sector for Senegal

Units (T = Tonne)	CO2 Fossil Fuel (1000 T)	CO2: Net Biogenic (3) (1000 T)	CO (1000 T)	HC (1000 T)	CH4 (1000 T)	Pb (2) (T)	NOx (1000 T)	N2O (1) (T)	SOx (2) (1000 T)	TSP (1000 T)	Global Warming Potential 100 Year Integration 1992 IPCC (1000 T Ceq)	1990 IPCC (1000 T Ceq
SUPPLY/TRANSFORMATION SECTORS												
Crude Oil Prod.	0										0	0
Nat. Gas Prod.	1						0		0		1	1
Charcoal Prod.		699	31	36	9		2			40	824	1374
Nat. Gas T&D Loss				1	1						10	30
Refinery	111		0	1	0		1		1		112	120
Electricity (SENELEC + Self-Gen)												
Diesels	57		0	0			1		0	0	57	58
Gas Turbines (Distillate)	49		0	0			0		0	0	49	49
Gas Turbines (Nat. Gas)	15		0				0				15	15
Steam Boilers (Fuel Oil)	740		0	0		0	2		10	1	740	741
Bagasse			0	0			0			3	1	5
TOTAL SUPPLY/TRANSFORMATION	**973**	**699**	**32**	**38**	**10**	**0**	**6**		**11**	**44**	**1833**	**2394**
DEMAND SECTORS												
Industry	313		0			0	1		3	0	314	314
Fisheries	164		8	3	0		1	3	0	0	178	221
Transport	878		20	3	0	16	5	10	1	1	914	982
Household	105	179	156	9	12		1	81	1	12	462	1126
Other	2								0		2	2
TOTAL DEMAND	**1462**	**179**	**185**	**16**	**12**	**16**	**8**	**94**	**5**	**13**	**2088**	**2645**
TOTAL SYSTEM	**2435**	**878**	**217**	**53**	**22**	**17**	**15**	**94**	**16**	**57**	**3921**	**5039**

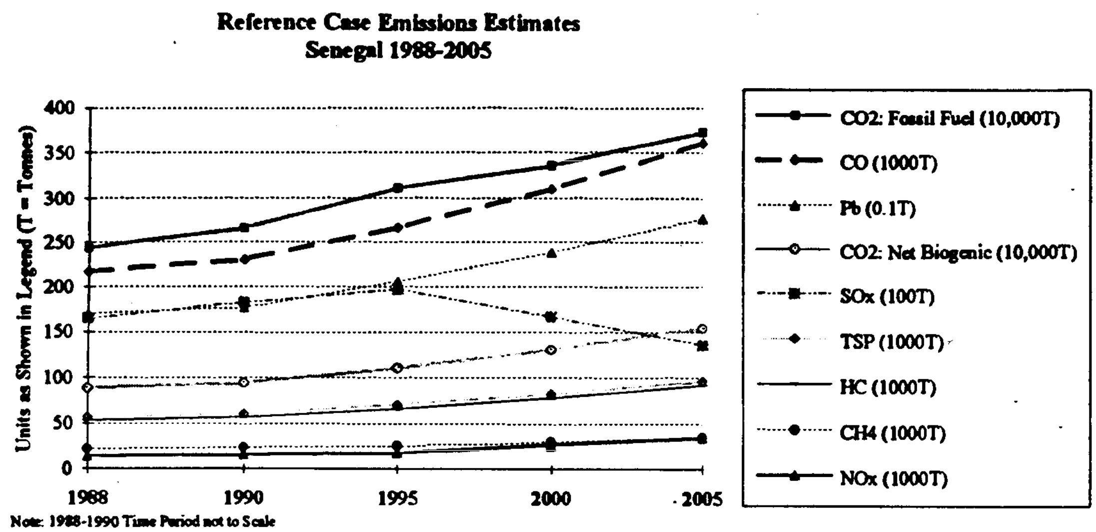
Blank entries indicate that no values have been entered (inadequate data or not an applicable category); zero values indicate a value of less than 0.5.

(1) N2O estimates were included only for recent household measurements (Smith et al., 1992), and are thus useful only for comparisons within this sec

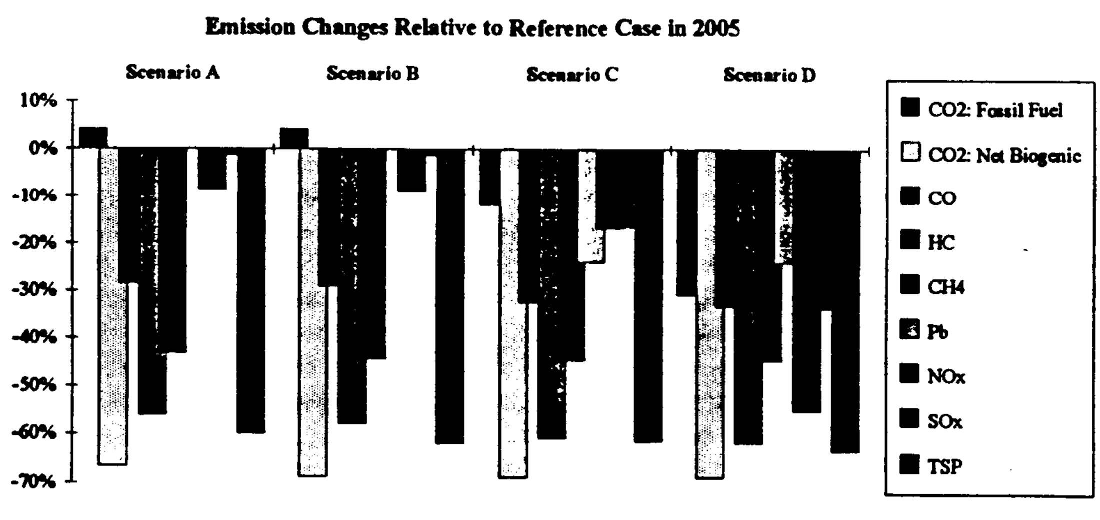
(2) Lead and Sulfur emissions will be directly proportional to their content in fuels used in Senegal.
Senegal purchases and produces petroleum products with a wide variation in sulfur content (heavy fuel oil sulfur content ranged from .1% to 3.3% fro
thus standard assumptions were made about sulfur content as shown in the annex tables (1% for heavy fuel oil etc.)

(3) All charcoal-related CO2 emissions reported under charcoal production, while household line reflects all firewood emissions.

The transport sector accounts for the largest share of current nitrogen oxide (NOx) emissions, a share that is likely to increase with urbanization, and increased traffic congestion. Fuel oil use in electric and industrial steam boilers is responsible for most sulfur oxide (SOx) emissions.

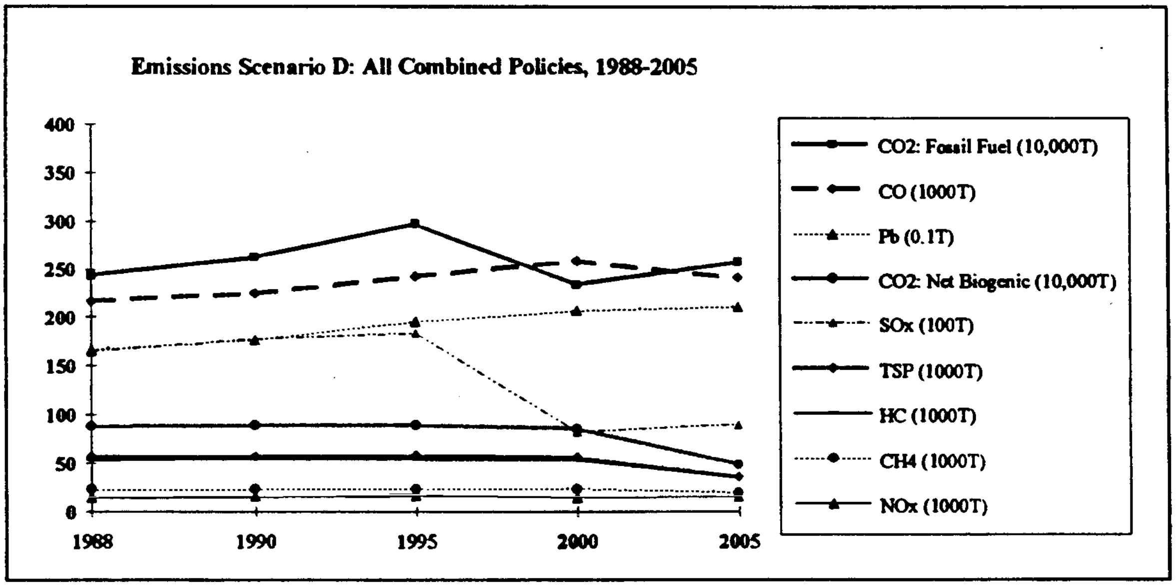


Under the reference case, emissions increase in all categories except sulfur oxides, as illustrated above. This decrease in sulfur oxides reflects assumptions regarding the use of lower sulfur fuels with newer electric generating units. Total carbon dioxide emissions in 2005 increase by 1.9 million tonnes, an increase of 59% over 1988 levels. The share of net biogenic emissions remains relatively constant at about 30% of the total throughout the period.

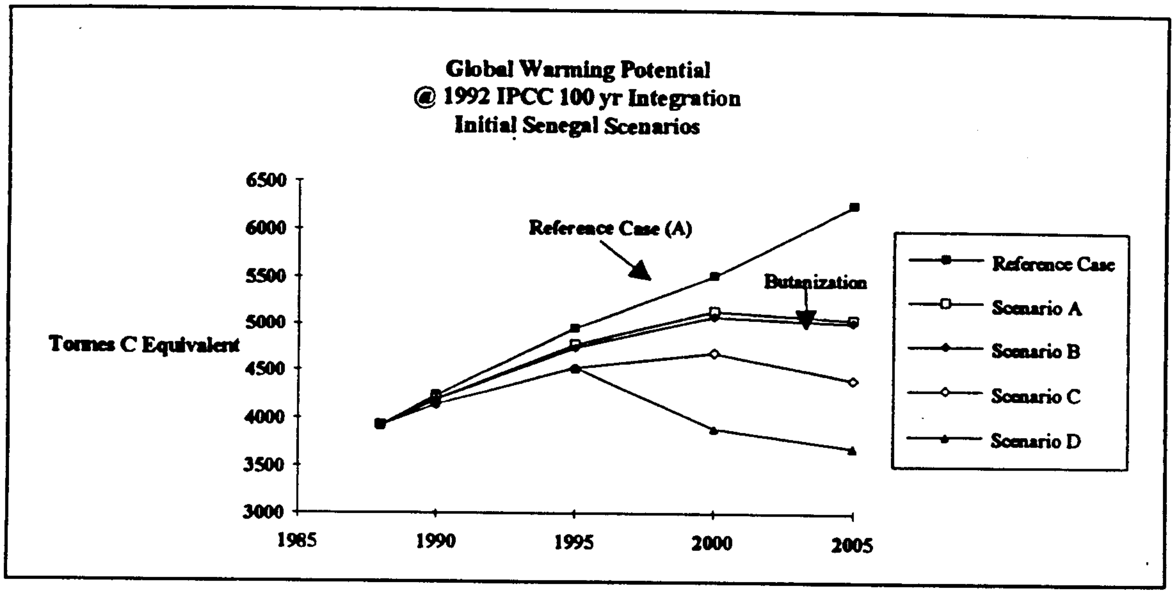


The policy scenarios result in significant decreases in all emission categories, as above below for 2005. The butanization scenario (A) reduces total carbon dioxide emissions by 0.9 million tonnes relative to the reference case in 2005, cutting in half the projected increase in reference case CO2 emissions. The decrease in net biogenic CO_2 of almost 70 percent shown above, far more than offsets the increase fossil fuel CO_2 emissions of about 4 percent. At the same time, total emissions of CO, HC, CH4, and TSP decrease from 28 to 56 percent relative to the reference case, as two major sources of these emissions, charcoal production and use, are greatly curtailed.

Scenario C results in an additional decrease of 0.6 million tonnes in fossil fuel CO_2 relative to the reference case in 2005, leading to only a 14% increase over total CO2 emissions over the 17 year study period. In addition, all other categories of emissions further decrease relative to the reference case. By avoiding oil-fired power plant emissions, hydro additions in Scenario D result in significant decreases in NOx, SOx, and CO2 emissions. Total CO2 emissions in the year 2005 decrease an additional 0.7 million tonnes to 3.1 million tonnes, an overall decline of 8% from 1988 levels. The emissions trajectories for Scenario D are shown below.



An interesting conclusion from this analysis is that many categories of environmental emission -- acid precursors, greenhouse gases, indoor and urban air pollutants -- and, by general implication, impact -- including human health and degradation -- could improve, relative to not only a reference case but to current conditions. In fact, if the strategies outlined above are otherwise desirable and achievable in practice, they could represent no or low regret options for abating greenhouse gas emissions. If successful, these combined policies could lead to stabilization of CO_2 and overall GWP at 1988 levels by 2005. Although not necessarily a policy objective that should be as relevant to a developing country with per capita commercial energy consumption one-tenth of the world average, this potential is nonetheless interesting from an international policy perspective. Many options to reduce emissions in the South, such as those illustrated here, could prove less expensive to implement than many discussed in the North, suggesting possibilities for mutually benficial assistance or transfer payments, if needed to overcome foreign exchange constraints or other obstacles to policy implementation.



More specifically, in the case of Senegal, we can look at the cost of greenhouse gas emission abatement associated with butanization, a policy with local benefits in addition to a potential global one. The table below indicates the fuel use and emissions associated with cooking a typical meal in Senegal, derived from field surveys using different stoves and fuels. Because of the much greater inefficiencies associated with charcoal production (kiln) and use, compared with LPG and kerosene production (refinery) and use, CO2 emissions are about 3-fold higher.[11] In terms of GWP, the contrast is even more dramatic, emissions are up to 6 times higher in the case of charcoal. Assuming that a 60 CFA/kg subsidy (the subsidy in 1988 was approximately 60-65 CFA/kg) is required to overcome barriers to fuel switching to LPG, this policy results in a cost of about $30 US per tonne of CO2 reduced, and slightly around $15 US per tonne of CO2 equivalent GWP.[12] This cost compares with the recently proposed European Community carbon/energy tax of $22/tonne by the year 2000. We do not suggest here that such an LPG subsidy is the best approach to encouraging substitution (indeed it may a relatively high cost option), but only one which has proven politically acceptable in practice (increasing charcoal prices could be much more difficult).

[11] Using the previous assumption that 50 percent of charcoal production involves unsustainable harvesting.
[12] This calculation assumes the following: 1) no free riders, that is, fuel switching would not occur in the absence of the subsidy; 2) switching occurs between the most commonly available charcoal and small LPG equipment (switching between the most efficient of each would have the same effect, at lower total cost); 3) the 50% non-renewable fraction stays constant. It does not include the cost of end-use equipment, which need to be added, but is unlikely to dramatically change the overall economics, as fuel costs dominate. The current subsidy is targetted to low and middle income families by providing the subsidy only for small stoves.

Comparative Emissions and Fuel Costs for Cooking a Typical Senegalese Dish

	Fuel Use per Dish	Recent Fuel Price	Fuel Cost Per Dish	Emissions per Dish	
				CO_2 (1)	GWP92
	kg	CFA/kg	CFA	kg	kg CO_2 eq
Charcoal					
Standard (Malgache)	0.77	64	49	3.48	6.83
Improved (Saakanal)	0.53	64	34	2.39	4.70
LPG					
Standard (Avg 3-6kg.)	0.36	120	43	1.12	1.14
Improved	0.25	120	30	0.78	0.79

Sources: ENDA, 1990; World Bank, 1989. Includes emissions from charcoal production and petroleum refining. With assumption of 50% of wood for charcoal harvested unsustainably.

7. Conclusions and Next Steps

The Phase I analysis has implemented an analytical framework to quantify some of the energy-environment implications of a few policy alternatives for Senegal. The methods elaborated here enable a rapid assessment of indicators for a few important environmental issues (air quality, greenhouse gas emissions, land degradation/deforestation), while not yet incorporating others, particularly those associated with hydroelectric and other non-combustion options. In addition, integrated scenario methods help to capture interactive effects among energy strategies, and to review them across a partial spectrum of environmental impact indicators. These methods do not substitute for, but rather to help identify where more thorough environmental assessment may be appropriate.

In particular, results of the preliminary scenarios, indicate that LPG substitution policies could actually reduce greenhouse gas emissions, while contributing to improvement of more important near-term environmental problems (e.g. rural ecosystem deterioration) in an African country such as Senegal. These policies may deserve additional attention and support from aid and funding sources, given their potential as low-cost contributors to reducing greenhouse gas emissions. (Further emissions testing, ground truthing on charcoal impacts, and comparison with other policies are needed to confirm these preliminary results.) The oil import and resulting foreign exchange impacts of increasing LPG use in households is inherently limited by the saturation of cooking demands to roughly 5 percent of future oil consumption.

A set of combined policies for Senegal could reduce future emissions and indicators for several environment impacts, relative to not only the reference case, but to current levels. At the same time, oil imports can be reduced by up to 30 percent relative to reference case levels in 2005, achieving the dual objectives of Senegal energy policy.

Several aspects need to be deepened and broadened for both application within Senegal and extension to other countries. Areas for Phase II activities will include several of the following objectives:

- elaborating a more detailed evaluation of energy use patterns and important driving variables (e.g. planned economic activity, demographic factors, pricing policies) and thereby improve the reference case;

- investigating additional technical and policy options, and applying cost-benefit analyses;

- incorporating other options of environmental improvement such as emission controls (e.g. for vehicles and power plants), improved biomass/forest management;

- revisiting the uncertainties associated with many of the emission factors developed here, including, in particular, better assessment and sensitivity analysis of the renewability of woodfuel production.

- attempting to incorporate, perhaps only in a qualititative fashion, some of the as yet unquanitified impacts (such as hydroelectric land use). Omitting such impacts risks giving an implicit advantage to resources and technologies whose impacts are most difficult to measure.

Finally, once emissions and impacts are estimated, these environmental consequences need to be internalized in the energy planning decisions, in either an ad hoc or systematic fashion. While risk and socioeconomic analysis can help to further translate various energy scenarios into employment, ecological, and human health and welfare impact estimates, balancing these impacts is inherently the domain of social values, typically resolved in a political process. Nonetheless, some systematic approaches have been developed. These include the monetization of externalities, and the use of point systems or weights to rate the relative importance of many of the factors listed above. In essence, they are the same process. In a more complex formulations, planners and analysts ascribe values to these factors and use multi-objective optimization programing to help determine the best outcome. (see discussion of multi-attribute assessment, in ADB, 1991).

Practical experience with all of these comparative approaches is relatively limited, with perhaps, the broadest being with recent efforts to monetize air emission impacts in the electric sector planning process, particularly in the U.S. (See Bernow et al., 1991). Efforts to establish taxes on woodfuel harvesting or sales, with the intent of reducing environmental impacts and potentially recycling the taxes for forest or demand management, are examples of monetizing externalities in current developing country practice. Phase II activities may also explore the applicability of these and other approaches to environmental externalities.

REFERENCES

Adegbulugbe, A.O. 1992. "Energy-Environmental Issues in Nigeria", paper presented at the International Energy Workshop, Harvard University, Cambridge, MA, June.

Amous, S. 1992. *Degradation De L'Environement au Senegal: Le Role de L'Energie*, Programme Energy-Environnement en Afrique (PEEA).

Asian Development Bank. 1991. *Environmental Considerations in Energy Development*, Energy and Industry Department. May.

Bernow, S. , Biewald, B., Marron, D. 1991. "Environmental Externalities Measurement: Quantification, Valuation, and Monetization", in *External Environmental Costs of Electric Power*, Hohmeyer, O., Ottinger, R., eds. Springer-Verlag, Berlin.

Bose, R.K., Srinivasachary, V. 1992. *Policies to Reduce Energy Use and Environmental Emissions in the Transport Sector: A Case of Dehli City*, Tata Energy Research Institute, New Dehli.

Busch, J., DuPont, P., Chirarattananon, S. 1991. *Conserving Electricity for Lighting in Thai Commercial Buildings: A Rewiew of Current Status, Potential, and Policies*, Lawrence Berkeley Laboratory, Berkeley, CA. Draft.

Busch, J. 1990. *From Comfort to Kilowatts: An Integrated Assessment of Electricity Conservation in Thailand's Commercial Sector*, Lawrence Berkeley Laboratory, Berkeley, CA. August.

Davidson, O., Karekezi, S. 1991. *An Energy Strategy for Environmentally-Sound Development in Sub-Saharan Africa*," African Energy Policy Research Network, September.

Diour, D. R. 1991. "Senegal: Strategie de l'Energie Domestique", SENELEC, paper submitted for the Seminar on Energy Planning and Policy, World Bank/EDI, June.

ENDA-TM. 1990. *L'Energie au Senegal*, Edition 1990, Programme Energie.

Environnement et Development Soutenu Dans La Region Soudano-Sahelien. 1991. *Synthese des Rapports Nationaux*. October.

Faiz, Asif. 1991. "Automotive Emissions in Developing Countries - Relative Implications for Global Warming, Acidification, and Urban Air Quality", paper presented at Conference on Transportation and Global Climate Change, Pacific Grove, CA. August.

Geller, H. 1991. *Efficient Electricity Use: A Development Strategy For Brazil*, ACEEE, Washington, DC.

Girod, J., Thomas, J.P., Sokona, Y., Diallo, S. 1991. *Les Performances du Systeme Electrique en Afrique de L'Ouest: Burkina Faso, Cote D'Ivoire, Mali, Niger et Senegal*, Draft Report, ENDA-TM, April.

Intergovernmental Panel on Climate Change. 1992. *Scientific Assessment of Climate Change, 1992 Supplement.* UNEP/WMO.

OECD/IPCC. 1991. *Estimation of Greenhouse Gas Emissions and Sinks: Final Report from the OECD Experts Meeting, 18-21 February 1991.* Prepared for the Intergovernmental Panel on Climate Change. August Revision.

O'Keefe, P., Raskin, P., Bernow, S. 1984. *Energy and Development in Kenya: Opportunities and Constraints*, Vol. 1, Energy, Environment, and Development in Africa, Beijer Institute, Stockholm. 190 pp.

Poole, A.D., Moreira J.R. 1992. "CO2 Emission Abatement" in *Global Greenhouse Regime: Who Pays?*, Draft report, Smith, K.R., Hayes, P., eds. Forthcoming.

Republique du Senegal. 1992. *Vers Un Developpement Durable*, National Report to UNCED, Rio de Janeiro, June.

Ribot, J. C. 1990. *Markets, States, and Environmental Policy: The Political Economy of Charcoal in Senegal*, Ph.D. Thesis, University of California, Berkeley.

Schipper, L., Meyers, S. 1992. *Energy and Human Activity: Global Trends and Prospects*, Cambridge University Press.

Sene, M. Gnansounou, E. 1990. "Localisation des Centres Electrifies et Non Electrifies", MASENS, Ecole Polytechnique Federale de Lausanne, April.

SENELEC. 1991. "Prevision a Long Terme de la Demande D'Electricite", Direction des Etudes Generales, Service Etudes Economiques, May.

Smith. K.R., Khalil, M.A.K., Rasmussen, R.A..et al. 1992. "Greenhouse Gases from Biomass and Fossil Fuel Stoves in Developing Countries: A Manila Pilot Study", forthcoming in *Chemosphere*.

Smith, K. R. 1987. *Biofuels, Air Pollution, and Health: A Global Review*, Plenum Press, New York, N.Y.

Subak, S., Raskin, P., Von Hippel, D. 1992. *National Greenhouse Gas Accounts: Current Anthropogenic Sources and SInks*. Stockholm Environment Institute.

Union of Concerned Scientists, Natural Resources Defense Council, Alliance to Sae Energy, American Council for an Energy Efficient Economy. 1991. *America's Energy Choices*. Union of Concerned Scientists, Cambridge, MA.

World Bank. 1991. *Environmental Assessment Sourcebook, Volumes I-3*, Environment Department, World Bank Technical Paper 139, Washington, D.C.

World Health Organization. 1989. *Management and Control of the Environment*, Report WHO/PEP/89, Geneva.

World Resources Institute. 1992. *World Resources 1992-93*, Oxford University Press, New York/Oxford.

Zhang, Z. 1991. *Evolution of Energy Demands and CO_2 Emissions in China Up to the Year 2030.* Netherlands Energy Research Foundation (ECN), Petten, The Netherlands.

ANNEX 1: SENEGAL ENERGY BALANCE, 1988

(Thousand Tonnes Oil Equivalent)

	Crude Oil	Gasoline	Kerosene	Diesel & Gasoil	Fuel Oil	LPG	Natural Gas	Electric	Vapor	Vegetal Waste	Firewood	Charcoal	TOTAL
INDIGENOUS	2.6						7.5		44.4	149.6	834.1		1038.2
EXPORTS		-30.3	-2.7	-120.5	-11.8	-0.3							-165.6
IMPORTS	729.5	2.0	44.4	106.1	64.1	20.8							966.8
TOTAL SUPPLY	**732.1**	**-28.3**	**41.7**	**-14.5**	**52.3**	**20.5**	**7.5**		**44.4**	**149.6**	**834.1**		**1839.4**
TRANSFORMATION													
Refinery (SAR)	-732.1	115.7	103.7	211.7	267.5	7.1							-26.4
Electricity (SENELEC)				-29.9	-226.7		-6.3	72.5					-190.4
Energy Sector Use								-5.2					-5.2
T&D Losses							-1.3	-9.2					-9.2
Electricity (Auto-Producers)				-6.0	-15.5			13.8	-44.4	-149.6			-201.7
Charcoal Production											-364.3	106.4	-257.9
FINAL CONSUMPTION		**87.4**	**145.5**	**161.3**	**77.6**	**27.6**		**71.9**			**469.8**	**106.4**	**1147.4**
Industry				26.0	77.6			32.4					136.0
Fisheries		15.6		38.5									54.1
Transport		71.8	134.3	96.8									303.0
Household			11.2			26.8		14.4			469.8	106.4	628.6
Other						0.8		25.1					25.8

Reformatted LEAP Energy Balance report; based on "L'Energie au Senegal - Edition 1990", ENDA-TM

ANNEX 2: OVERVIEW OF LEAP/EDB

The structure and design of the Long-term Energy Alternatives Planning (LEAP) and Environmental Data Base (EDB) system is described in the adjoining box below. The design of LEAP emphasizes a number of methodological considerations, including:

- the desirability of using the **scenario approach** to test the consequences of alternative assumptions about the future;
- the need for **integrated energy-environment planning** capabilities;
- the role of the **end-use, needs-driven approach** for performing energy assessments;
- the importance of **flexibility** and **user-friendliness** to make the system accessible to users of diverse backgrounds in a variety of geographical and institutional contexts; and
- the requirement that the computer applications and **data development** evolve together, enabling effective use of the system with other limited or extensive data.

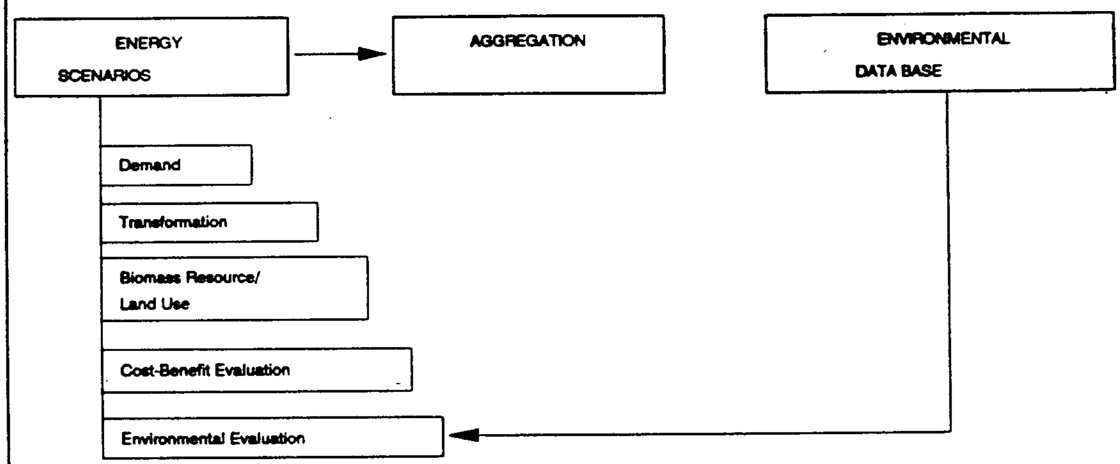
As a `bottom-up' modelling system, LEAP's principal elements are the energy and technology characteristics of end-use sectors and supply sources. LEAP has three specific strengths. First, it allows, but does not require, very detailed specifications for key physical parameters in each end-use sector, based on upon locally available data. Thus, our scenarios can embody the impact of a variety of factors--including technological change, demographic variables, and structural shifts in the economy--on energy use. Second, the accounting framework in LEAP enables its results to be internally consistent; that is, assumptions made about energy use in one sector are consistent with those made in another. For example, a reduction in petroleum use in the transport sector automatically leads to a reduction in distribution losses and energy use for petroleum refining. Finally, with its links to the Environmental Data Base, LEAP can track the pollution resulting from each stage of the fuel cycle, including the reduced emissions from extraction, processing, distribution, and combustion that would result from more efficient use of fossil fuel.

While LEAP is capable of incorporating econometric equations (e.g., production functions), it is not an econometric model that determines future energy use based on historical data. A fundamental aspect of such models is the presumption that trends observed in the past will continue into the future. However, often, and particularly in African countries, detailed and accurate time-series data are unavailable. Furthermore, energy use in developing economies change rapidly due to considerations such as improved fuel distribution or the addition of a single energy facility or factory in a small country, both factors that can be difficult to reflect in traditional econometric equations.In addition, because econometric models, often considered `top down' models in contrast to the `bottom-up' approach used in LEAP, are based upon historical relationships, they have difficulty reflecting changes in the variety of technologies available, or other structural shifts (e.g. eating habits to quicker cooking foods to changes in the industrial base) that differ from historical trends. For longer term analysis, it becomes increasingly difficult to expect that historically-derived econometric relationships will continue to hold. In addition, due to their usual high level of sectoral aggregation, econometric models forego detail about changes specific to subsectors and energy end-uses such as lighting or process heat. Such changes can have major effects on overall energy use.

THE STRUCTURE OF LEAP

LEAP is structured as a family of easy-to-use microcomputer programs, the LEAP energy planning system is suitable for performing energy assessments in developing or industrialized countries, for multi-country regions, or for local planning exercises. It consists of three groups of main programs: Energy Scenario, Aggregation, and the Environment (and an optional add-on group for making macroeconomic projections). The Energy Scenario programs address the main components of an integrated energy analysis: demand analysis, energy conversion, and resource assessment. This group consists of three programs for **building** scenarios (Demand, Transformation, Biomass/Land Use), a program for **reporting environmental emissions** and one for **comparing and evaluating scenario costs and impacts**. The planner uses the scenario building programs to develop current energy balances, projections of supply and demand trends, and scenarios representing the effects of energy policies, plans and actions. The Environmental and Evaluation programs compute the **physical** impacts of moving from one scenario to another, the **economic** costs and benefits, and the **environmental** emissions. The **Aggregation** program assemble area level (district, nation, region) energy accounts and projections into multi-area results. The Environmental Data Base, **EDB**, provides a comprehensive summary of the information linking energy production, conversion and consumption activities to air and water emissions, and other environmental and health consequences, that can be linked to energy scenarios to provide measures of the environmental consequences of alternative futures.

LEAP PROGRAM STRUCTURE



The **Demand** program provides a framework for disaggregated, end-use analysis of final energy requirements. Data are assembled in a hierarchical format, based on four levels: ***Sectors***, ***Subsectors***, ***End-uses***, and ***Devices***. Depending on data availability and analytical choices, the user can define an appropriate structure and select from among several options for making future projections (e.g., growth rates, fixed targets, elasticity relationships, etc.). The **Transformation** program simulates the energy sector conversion processes that turn primary resources, such as hydropower and crude oil, into final fuels, such as electricity and kerosene. The program compares the primary resources and fuel imports and exports required to provide the final fuel consumption calculated by the Demand program. Major transformation processes are handled by specialized modules — e.g., electricity production, ethanol plant, oil refining, oil and gas production, coal mining, charcoal kilns, biogas production, etc. — while others may be user defined. The **Biomass Resource/Land Use** program examines the impact of biomass requirements and land-use changes on the biomass resource base. Biomass projections are based on the inventory of wood stocks and yields, crop yields, crop residue availability, and dung production, at various levels of spatial detail. The **Environment** program links the physical processes created in the scenario programs to EDB, to track the emissions loadings and impacts of alternative scenarios. The **Evaluation** analysis includes the impacts of technology and project costs, inflation, discount rates, and foreign exchange components of each option, and can account for either market or shadow prices, as well as environmental externality costs, if included.

Unlike 'top-down' equilibrium models such as Edmonds-Reilly, LEAP does not simulate price and income interactions to seek a 'market equilibrium' between supply and demand for each scenario.[1] As energy efficiency increases, for example, the demand for energy falls and some reduction in fuel prices might be expected. Likewise, as the cost of energy services is reduced by the use of least-cost technologies, the demand for energy can, in turn, rise somewhat. However, such interactive relationships between price and demand are notoriously difficult to accurately quantify, and the high variation among elasticities can lead to dramatically different results.

Optimization models find the economically optimal mix of technologies for a set of inputs under given constraints. This approach can be rich in technical detail and forward-looking in its technological assumptions. The complexity of the mathematical algorithms, however, often requires that key aspects of the energy system be simplified. Many policy and behavioral variables and constraints are difficult to parameterize and incorporate in these analyses. Optimization models can be highly sensitive to relative price forecasts and the expected costs of technologies, which are, by definition, uncertain.

For these reasons, we have chosen the end-use 'bottom-up' approach, embodied in LEAP, specifically to enable us to incorporate and simulate several important effects, including technological improvements and transitions, the limits imposed by saturation of several energy-intensive activities, and structural shifts among economic sectors and subsectors. The end-use approach allows us to consider numerous detailed potential steps, such as efficiency improvements and fuel switching opportunities, as they have been identified in other studies.

---

[1] Market equilibrium itself can be elusive in reality. Essentially, it assumes perfectly operating markets, and the absence of well-known market failures, such as imperfect information or the lack of consideration of the value of clean air, water, and soil (i.e. externalities).

PARTIAL LISTING OF CURRENT LEAP/EDB RECIPIENTS AND USERS

Country	Organization
PHILIPPINES	Office of Energy Affairs
ZAMBIA	Ministry of Power, Transport, and Communications
ZIMBABWE	Ministry of Energy, Water Res. and Development
ZIMBABWE	Zimbabwe Electric Supply Authority
ETHIOPIA	Ethiopian Energy Authority, Ministry of Mines and Energy
DJIBOUTI	Institut Superieure pour les Etudes de la Recherche Sc.
SENEGAL	Ministere de l'Artisanat, Ministere du Plan
TANZANIA	Ministry of Energy and Minerals
TANZANIA	University of Dar-es-Salaam
ECUADOR	Organizacion Latinoamericana de Energia
INDIA	Tata Energy Research Institute
NETHERLANDS	Energy Study Centre (ESC), Netherlands Energy Research Foundation
BRAZIL	Companhia Energetica de Minas Gerais
COSTA RICA	Direccion Sectorial de Energia
INDIA	Indian Institute of Management
HUNGARY	Institute for Thermal Engineer, Technical University of Budapest
MEXICO	Dir. Gen. de Politica Energia, Secretaria de Energia, Minas, e Industria Parastatal
HUNGARY	Central Mining Development Institute
ECUADOR	Instituto Nacional De Energia
POLAND	Central Mining Institute
CZECHOSLOVAKIA	Government of Czechoslovakia (Energy/Environment Plan)
INDIA	Dpt. of Management Studies, Indian Institute of Science
DENMARK	Energy Systems Group, RISO National Laboratory
ROMANIA	Government of Romania (Energy/Environment Planning)
THAILAND	Regional Wood Energy Development. Prog., FAO
SRI LANKA	Ministry of Power and Energy
PERU	Industrial Department, Junta del Acuerdo de Cartagena
ANGOLA	Technical And Administrative U, SADCC Energy Sector
YUGOSLAVIA	Electrotechnickog fakulteta,
BOLIVIA	Direccion National de Electric, Ministerio de Energia e Hidrocarburos
BRAZIL	Secretaria Nacional de Energia, Departmento Nacional de Combustibles
COLOMBIA	Officina de Planification, Ministerio de Minas y Energia

ANNEX 3: Calculation of CO_2 Coefficients

To establish a consistent set of coefficients for carbon dioxide emissions, the following procedure was used. First, a set of carbon contents by fuel was compiled from the literature[2] and, in some cases, by calculations based on fuel molecular weights. Next, these carbon fractions were multiplied by the ratio of CO_2 to carbon molecular weights (44/12) and by an assumed average fraction of fuel that goes through burners unoxidized. This 'unburnt' fraction of fuel carbon, which is assumed to be primarily emitted as soot and ash, was assumed to be 1.0 percent for each type of fuel While this assumption is consistent with literature estimates (e.g. Grubb, ibid; OECD, 1991, Background Document for the February, 1991 Workshop on Emissions Methodology, Chapter 2: "Emissions from Energy Production and Consumption"), very little recent empirical work appears to have been done to quantify the fraction of carbon left unoxidized in soot and ash after fuel combustion. Finally, for types of fuel use (e.g. automobiles, wood stoves) where CO emissions represent a significant (c. 0.5 percent or greater) fraction of total carbon emissions, the fraction of carbon emitted as carbon monoxide was subtracted from the CO_2 emission coefficient. This avoids the problem of double-counting carbon emitted as CO. The table below shows the fuel carbon and energy content assumptions used in this study, as well as the carbon dioxide emissions (assuming complete combustion) per unit fuel energy.

CARBON AND ENERGY CONTENT ASSUMPTIONS, AND CO_2 EMISSIONS PER UNIT ENERGY[3].

FUEL	CARBON CONTENT	ENERGY CONTENT	kg CO_2/GJ
NATURAL GAS	0.51 kg/m^3	0.03545 GJ/m^3	52.8
GASOLINE	84.6 % by wt	43.96 GJ/tonne	70.6
KEROSENE/JETFUEL	85 % by wt	43.2 GJ/tonne	72.1
DIESEL/GAS OIL	86.5 % by wt	42.5 GJ/tonne	74.6
RESIDUAL/FUELOIL	84.4 % by wt	41.5 GJ/tonne	74.6
LPG/BOTTLED GAS	82 % by wt	45.54 GJ/tonne	66.0
CRUDE OIL	83.5 % by wt	41.87 GJ/tonne	73.1
COAL BITUMINOUS	74.6 % by wt	29.31 GJ/tonne	93.3
COAL LIGNITE	31 % by wt	11.3 GJ/tonne	100.6
FIREWOOD	43.8 % by wt	16 GJ/tonne100.4	
ETHANOL[a]	52.2 % by wt	0.0219 GJ/l110.8	

[a] Ethanol and Methanol carbon contents converted to CO_2/GJ using densities of 0.789 and 0.796 kg/l, respectively
[b] This table shows only gross CO_2 emissions from fuel consumption, and does not include CO_2 impacts from fuel production (e.g., hydrogen from coal)
[c] Based on net or lower heating values.

---

[2] Major sources for carbon contents included Grubb, M., 1989; "On Coefficients for Determining Greenhouse Gas Emissions from Fossil Fuel Production and Consumption", P. 537 in Energy Technologies for Reducing Emissions of Greenhouse Gases. Proceedings of an Experts' Seminar, Volume 1, OECD, Paris, 1989, and ORNL, 1989; Estimates of CO2 Emissions from Fossil Fuel Buming and Cement Manufacture..., G. Marland et al of Oak Ridge National Laboratory, May 1989, ORNL/CDIAC-25.

[3] This is possible because petroleum is 80-85 percent carbon and most (32/44) of the mass of CO_2 comes from oxygen, which is principally derived from the air in which the fuel is combusted, and not from the fuel itself.

ANNEX 4: Review of Household Emission Factors

Type	Region	Source	Original Reference	Unit	CO2	CO	CH4	HC	NOx	SOx(1)	TSP	N20
WOOD												
Default	Senegal	Best Guess		g/kg	1420	100.0	9.0	7.5	0.8	0.5	10.00	0.06
Manila	Phil.	Smith, 1992		g/kg	1620	100.0	9.0	13.0				0.06
Manila (5% C in ash/TSP)	Phil.	Smith, 1992		g/kg	1560	99.0	8.0	12.0				0.06
Generic Wood Stove	------	Ellegard, 1989		g/kg	1400	121.0		3.9	0.8	0.4	11.40	
Generic Tropical Wood Stove	------	Smith, 1987		g/kg	1460	80.0		7.5	0.7	0.6	9.00	
Chula 1	India	Smith, 1987	Butcher, 1984	g/kg	1460	72-92					4.2-9.9	
Chula 2	India	Smith, 1987	Butcher, 1984	g/kg	1480	66-76					8.7-9.1	
3 Stone Fire		Smith, 1987	Butcher, 1984	g/kg	1460	39-106					2.9-15	
Metallic Stove		Smith, 1987	Ahuja, 1987	g/kg	1560	13-22					1.3-2.6	
Tara ("Improved Stove")		Smith, 1987	Ahuja, 1987	g/kg	1540	23-37					1.1-2.5	
CPS ("Improved Stove")		Smith, 1987	Ahuja, 1987	g/kg	1490	48-67					1.8-3.8	
CPRI ("Improved Stove")		Smith, 1987	Butcher, 1984	g/kg	1420	86-113					0.3-8.3	
CHARCOAL												
Default	Senegal	Best Guess		g/kg	2760	247.0	8.0	4.0		0.7	2.40	0.06
"Haiti"	Haiti	Ellegard, 1989	Islam, 1987	g/kg	2780	264.0				0.7	2.40	
Manila	Phil.	Smith, 1992		g/kg	2740	230.0	8.0	4.0				0.06
LPG												
Default	Senegal	Best Guess		g/kg	2950	24.0	0.0	3.0	2.0	0.0	0.06	0.03
Manila	Phil.	Smith, 1992		g/kg	3110	24.0	0.0	3.0				0.03
All-purpose, Generic, Uncontrolle	------	USEPA, 1985		g/kg	2980	0.4	0.1	0.2	2.0	0.0	0.06	
KEROSENE												
Default	Senegal	Best Guess		g/kg	3010	50.0	1.0	11.0	0.6	17.0	4.00	0.05
Manila	Phil.	Smith, 1992		g/kg	3030	38.0	1.0	11.0				0.05
Kerosette-type Stove		Smith, 1987	TERI, 1987	g/kg	2980	67.0					5.00	
Nutan		Smith, 1987	TERI, 1987	g/kg	3030	41.0					2.80	
Generic Furnace		WHO, 1982		g/kg	3090	0.3		0.4	2.3	17.0	3.00	
Radiant Stove		Smith, 1987		g/kg	3090	4.5			0.6		0.02	
Convective Stove		Smith, 1987	Lionel, 1985	g/kg	3090	0.0			0.1		0.02	
Multistage Stove		Smith, 1987	Lionel, 1985	g/kg	3090	0.1			0.1			
OTHER BIOMASS												
Coconut Husk Stove		Smith, 1987		g/kg	1220	110.0					35.00	
Dung												
COAL												
Generic DC Coal Stoves		USEPA, 1989		g/kg	2550	1050.0	0.0		5.2			
Handfired Bituminous		Ellegard, 1989	USEPA, 1985	g/kg	2630	48.5	4.0	15.8	2.9	14.6	10.80	
Handfired Anthracite		Ellegard, 1989		g/kg	2830	138.0		5.8	0.9	13.3	0.70	
Mafalfa		Ellegard, 1989		g/kg	2580	80.0		5.9	6.0	12.2	2.00	
Maxaquene		Ellegard, 1989		g/kg	2530	112.0		1.1	3.4	7.2	6.30	
Indian Stove		Smith, 1987		g/kg	2520	120.0		10.0	2.0	10.0	1.20	
NATURAL GAS												
Generic Cooking				g/cubic mete	1850	9.8		0.2	0.4		0.02	

(1) SOx emissions will depend on S content of local fuel used.

ANNEX 7: COEFFICIENTS USED FOR SENEGAL TRANSFORMATION DEVICES

EDB SOURCE CATEGORY	UNITS	CO_2-N	CO_2-B	CO	HC	CH_4	PB	NO_x	PT	SO_x
Fuel Dist Losses[1]										
Petroleum Prods	g/l	N/A	N/A	N/A	714	9.18	N/A	N/A	N/A	N/A
Natural Gas	g/l					0.572				
Charcoal Prod										
Kilns-Firewood/Generic, No EC	g/kg[2]	N/A	N/D	170	193	50.5	N/D	12.0	217	N/D
Electricity Production (per input fuel)										
Engine-Diesel/Generic	g/l	2170	N/A	12.2	3.85	N/D	N/D	56.2	4.01	3.74
Turbine-Oil/Generic, No EC	g/l	2730	N/A	1.85	0.572	N/D	N/D	8.12	0.599	16.8[3]
Turbine-Natural Gas/Generic, No EC	g/l	1.85	N/A	1.8E-3	2.0E-4			6.6E-3	2.2E-4	9.6E-6
Steam-Resid Oil/Generic, #6 Oil	g/l	2910	N/A	0.599	9.11E-2	N/D	5.03E-4	8.03	1.56[3]	19.1[3]
Steam-Bagasse/Generic	g/kg	N/A	*740*	1.0	1.0	N/D	N/D	0.6	8.0	N/D
Refinery										
Standard/Generic	g/kg[5]	152	N/A	0.172	0.92	8.87E-2	N/D	0.72	N/D	0.84
Natural Gas Production										
Natural Gas/Onshore	g/l	0.107		6.1E-5	1.9E-5	3.2E-4	N/D	2.7E-3	6.1E-5	4.6E-2
Crude Oil Production										
Crude Oil/Onshore	g/kg4	25.6		0.019	0.40	0.21	N/D	0.71	0.13	0.52

N/A = Not Applicable; N/D = No Data Available. All Emissions are per unit fuel input, unless otherwise noted.

Abbreviations for Emissions: CO_2-N = Non-biogenic (fossil-fuel) Carbon Dioxide, CO_2-B = Biogenic (biomass-fuel) Carbon Dioxide, CO = Carbon Monoxide, H
Methane, PB = Lead, NO_x = Nitrogen Oxides, PT = Particulates, SO_x = Sulfur Oxides.

Abbreviations used in Source Categories: No EC = No Emission Controls

1 Grams of emissions per volume lost.
2 Grams of emissions per kilogram of charcoal produced.
3 Based on a sulfur content of 1.0% S by weight.
4 Grams emitted per amount (crude oil or natural gas) produced.
5 Grams of emissions per kg incoming crude oil.

ANNEX 8: Initial LEAP/EDB Scenarios for Senega Energy-Related Air Emissions

(Thousand Tonnes per Year)

Reference Case	1988	1990	1995	2000	2005
CO2: Fossil Fuel	2435	2652	3108	3357	3721
CO2: Net Biogenic (Biomass/Deforestation)	878	937	1104	1302	1538
CARBON MONOXIDE (CO)	217	230	266	310	360
HYDROCARBONS (HC)	53	57	66	78	92
METHANE (CH4)	22	23	26	30	35
LEAD (Pb)	0.017	0.018	0.021	0.024	0.028
NITROGEN OXIDES (NOx)	15	16	18	27	35
NITROUS OXIDE (N2O)	0.094	0.099	0.114	0.130	0.150
SULFUR OXIDES (SOx)	16	18	20	17	14
PARTICULATES (TSP)	57	60	70	82	96

Scenario A: Butanization					
CO2: Fossil Fuel	2435	2671	3187	3516	3875
CO2: Net Biogenic (Biomass/Deforestation)	878	892	910	900	515
CARBON MONOXIDE (CO)	217	225	247	269	257
HYDROCARBONS (HC)	53	55	56	58	40
METHANE (CH4)	22	23	23	24	20
LEAD (Pb)	0.017	0.018	0.021	0.024	0.028
NITROGEN OXIDES (NOx)	15	15	18	26	32
NITROUS OXIDE (N2O)	0.094	0.099	0.111	0.125	0.134
SULFUR OXIDES (SOx)	16	18	20	17	13
PARTICULATES (TSP)	57	58	60	60	39

Scenario B: Improved Biomass Use Efficiency + Scenario A					
CO2: Fossil Fuel	2435	2671	3187	3516	3875
CO2: Net Biogenic (Biomass/Deforestation)	878	886	886	854	485
CARBON MONOXIDE (CO)	217	225	245	266	255
HYDROCARBONS (HC)	53	55	55	56	39
METHANE (CH4)	22	23	23	24	20
LEAD (Pb)	0.017	0.018	0.021	0.024	0.028
NITROGEN OXIDES (NOx)	15	15	18	26	32
NITROUS OXIDE (N2O)	0.094	0.098	0.111	0.124	0.134
SULFUR OXIDES (SOx)	16	18	20	17	13
PARTICULATES (TSP)	57	57	58	57	37

Scenario C: Improved Efficiency -- All Demand Sectors + Scenario B					
CO2: Fossil Fuel	2435	2623	2974	3126	3282
CO2: Net Biogenic (Biomass/Deforestation)	878	886	886	854	485
CARBON MONOXIDE (CO)	217	225	243	260	244
HYDROCARBONS (HC)	53	54	55	54	36
METHANE (CH4)	22	23	23	24	20
LEAD (Pb)	0.017	0.018	0.020	0.021	0.021
NITROGEN OXIDES (NOx)	15	15	17	24	29
NITROUS OXIDE (N2O)	0.094	0.098	0.110	0.122	0.129
SULFUR OXIDES (SOx)	16	18	18	15	11
PARTICULATES (TSP)	57	57	58	58	37

Scenario D: Hydroelectricity + Scenario C					
CO2: Fossil Fuel	2435	2623	2974	2339	2576
CO2: Net Biogenic (Biomass/Deforestation)	878	886	886	854	485
CARBON MONOXIDE (CO)	217	225	243	258	241
HYDROCARBONS (HC)	53	55	55	54	35
METHANE (CH4)	22	23	23	24	20
LEAD (Pb)	0.017	0.018	0.020	0.021	0.021
NITROGEN OXIDES (NOx)	15	15	17	15	16
NITROUS OXIDE (N2O)	0.094	0.098	0.110	0.122	0.129
SULFUR OXIDES (SOx)	16	18	18	8	9
PARTICULATES (TSP)	57	57	58	56	35

Annex 5: Review ofTransportation Emission Factors

Type	Source	Original Reference	Unit	CO2	CO	HC	CH4	NOx	SOx	TSP	Pb	N20	S Content
AUTOMOBILES													
Gasoline													
Senegal - Mix of India and Netherlands, IPPC/Uncontrolled			g/kg	2660	263	38.5	1.38	32.4	0.39	0.50	0.243	0.04	
Car-India	Bose et al, 1992	IIP	g/kg (1)		354	53		23.1	0.78		0.243		0.08%
Jeep-India	Bose et al, 1992		g/kg (1)		367	54		24.0	0.78		0.243		0.08%
Car- US - Uncontrolled	IPCC, 1991	EPA, 1989	g/kg		323	50.3	1.38	17.0				0.04	
Car-US - 3 Way Catalyst	IPCC, 1991	EPA, 1989	g/kg		50	10.5	0.32	7.9				0.30	
Car-Netherlands: 1985 Fleet, 1.4-2 l engine	EEC, 1988		g/kg (2)		171	24		41.7		1.01			
US Medium, 27 mpg, Uncontrolled	OECD, 1986		g/kg	2470	380	30		48.5	1.24	0.32			
1965 US Em. stand., Emissions in 90, leaded	USEPA, 1985		g/kg	2160	582	75		169.0		0.96	0.027		
1975 US Em. stand., Emissions in 90, unleaded	USEPA, 1985		g/kg	2680	251	33		13.5		0.16	0.004		
1985 US Em. stand., Emissions in 90, unleaded	USEPA, 1985		g/kg	2920	97	12		8.3		0.27	0.004		
1990 US Em. stand., Emissions in 90, unleaded	USEPA, 1985		g/kg	3050	13	7		4.6		0.30	0.004		
Diesel													
Senegal - Mix of India and Netherlands, IPPC/Uncontrolled			g/kg	3140	12	8	0.06	11	7.13	4.98		0.08	
Jeep-Diesel	Bose et al, 1992		g/kg (1)		3	1		5.1	7.13	0.17			0.75%
Car - US - Advanced Control	IPCC, 1991	EPA, 1989	g/kg	3188	11	3.6	0.12	8.0				0.08	
Car - US - Uncontrolled	IPCC, 1991	EPA, 1989	g/kg	3188	6	3.1	0.06	6.1				0.08	
Car-Netherlands: 1985 Fleet, 1.4-2 l engine	EEC, 1988		g/kg (2)		22	15		15.9		9.78			
MOTORCYCLE/OTHER													
Gasoline													
2 Wheeler - India	Bose et al, 1992		g/kg (1)		519	324		n/a	0.82		0.254		0.08%
Motorcycle - US - Uncontrolled	IPCC, 1991	EPA, 1989	g/kg	3172	405	111.0	5.60	3.2				0.04	
BUSES													
Diesel													
India	Bose et al, 1992		g/kg (1)		22	8		40.9	7.13	0.17			0.75%
LIGHT DUTY VEHICLES (LDV)													
Gasoline													
LDV - US - Uncontrolled	IPCC, 1991	EPA, 1989	g/kg	3172	303	58.1	1.18	17.9				0.04	
LDV - US - Advanced Three-Way Catalyst	IPCC, 1991	EPA, 1989	g/kg	3172	58	9.4	0.50	8.4				0.30	
TRUCKS/HEAVY DUTY VEHICLES (HDV)													
Diesel													
HDV - US - Uncontrolled	IPCC, 1991	EPA, 1989	g/kg	3188	22	7.6	0.26	42.9				0.08	
HDV - US - Advanced Control	IPCC, 1991	EPA, 1989	g/kg	3188	22	4.1	0.19	16.3				0.08	
BOATS													
Gasoline													
Outboard Engine	EPA, 1985		g/kg	2240	534	178		1.1	1.04				0.00043
Diesel													
Best Guess				3120	11	2.7	0.23	35	7.82	2.07		0.08	
Boats	IPCC, 1991	EPA, 1989	g/kg	3188	21	4.9	0.23	67.5				0.08	
Commercial Steamships	EPA, 1985		g/kg	3140	1	0.4		3.3	7.82	2.07			

(1) Converted from g/l using a density .74 kg/l for gasoline, .87kg/l for diesel.

ANNEX 6: COEFFICIENTS USED FOR SENEGAL DEMAND DEVICES: INDUSTRY, HOUSEHOLD, AND SERVICES SECTORS

EDB SOURCE CATEGORY	UNITS	CO_2-N	CO_2-B	CO	HC	CH_4	PB	NO_x	TSP	SO_x
Industry										
Std Equip./Boiler-Wood/Small (not yet used)	g/kg	N/A	1590	2.0	0.7	N/D	N/D	0.34	4.4	7.5E-2
Standard Equip./Boiler-Dist Oil/Generic	g/l	2730	N/A	0.599	2.4E-2	7.7E-3	N/D	2.4	0.24	17.3[1]
Standard Equip./Boiler-Resid Oil/# 6 Oil	g/l	2910	N/A	0.599	3.35E-2	N/D	5.03E-4	6.59	1.44[1]	19.1[1]
Commercial/Services/Other										
Standard Equip./LPG/Generic*[check]*	g/l	1610	N/A	0.234	5.99E-2	N/D	N/D	0.899	0.222	10.4[2]
Standard Equip./Engine-Diesel/Generic	g/l	2710	N/A	12.2	3.85	0.447	N/D	56.2	4.01	3.74
Standard Equip./Engine-Gasoline/Generic	g/l	1530	N/A	472	17.7	N/D	N/D	12.2	0.775	0.636
Standard Equip./Boiler-Res. Oil/# 6 Oil	g/l	2910	N/A	0.599	0.135	N/D	5.03E-4	6.59	1.44	19.1[2]
Other (Non-Road) Transport										
Air/Jets/All	g/l	2490	N/A	4.41	N/D	7.35E-2	N/D	10.6	N/D	N/D
Rail/Freight-Diesel/2-stroke	g/l	2720	N/A	7.90	18.0	N/D	N/D	42.0	3.0	6.8[1]

N/A = Not Applicable; N/D = No Data Available.
All Emissions are per unit fuel input, unless otherwise noted.

Abbreviations for Emissions: CO_2-N = Non-biogenic (fossil-fuel) Carbon Dioxide, CO_2-B = Net Biogenic (biomass-fuel) Carbon Dioxide, CO = Carbon Monoxide, HC = Total Hydrocarbons, CH_4 = Methane, PB = Lead, NO_x = Nitrogen Oxides, TSP = Particulates, SO_x = Sulfur Oxides.

[1] Based on a sulfur content of 1.0% S by weight.
[2] Based on a sulfur content of 0.00044% S by weight.